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TECHNICAL MEMORANDUM II

CHARACTERISTICS RELEVANT TO RELEASES OF THREE GENERIC CANADIAN URANIUM TAILINGS SITES

8299

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THE TECHNOLOGY OF URANIUM TAILINGS COVERS
&
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THE STABILITY OF CONTROL STRUCTURES
FOR URANIUM MILL TAILINGS

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MICROMEDIA

PREFACE

This technical memorandum is the second in a series of five technical memoranda which document the data, technology and evaluation studies undertaken to evaluate the long term stability of "Covers" and "Control Structures" for Canadian uranium mill tailings. The technical memoranda are:

Technical Memorandum	Title
TM I	Canadian Uranium Tailings Deposits and Structures
TM II	Characteristics Relevant to Releases of Three Generic Canadian Uranium Tailings Sites
TM III	Methodology for Stability and Release Rate Evaluation
TM IV	Assessment of Alternative Evaluation Methods and Alternative Stabilization Practices
TM V	Evaluation of Cover and Structure Stability on Three Generic Canadian Uranium Tailings Sites

The conclusions reached and observations made as a result of these studies are summarized in two reports entitled:

REPORT 58901 THE TECHNOLOGY OF URANIUM TAILINGS COVERS

REPORT 58902 THE STABILITY OF CONTROL STRUCTURES FOR URANIUM MILL TAILINGS

This technical memorandum describes the characteristics of the tailings deposits and retention structures for three generic Canadian uranium tailings sites. Three different typical but non-specific generic tailings sites are described; one is typical of the Ontario deposits near Elliot Lake and two are typical of the Saskatchewan deposits. The evaluation studies undertaken in TM V are based on the characteristics defined for these three generic sites.

ACKNOWLEDGEMENTS

This study was conducted over a period of three months during which a large amount of data had to be obtained, reviewed and evaluated. It was only possible to complete the study in this short time period because of the willing and effective support provided by the Canadian uranium mining companies who were approached to provide data. Assistance was also provided in the review of the draft documents for this study by individuals employed by these mining companies.

We acknowledge with sincere appreciation the contributions of all who contributed to the study, of which the following made particularly large contributions:

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This study was guided by the Scientific Authority, Mr. Grant Feasby, and his prompt and effective guidance, review and comment contributed largely to its successful completion.

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TECHNICAL MEMORANDUM II: CHARACTERISTICS RELEVANT TO RELEASES OF THREE GENERIC CANADIAN URANIUM TAILINGS SITES

II.1.0 SELECTION OF THE THREE GENERIC SITES

II.1.1 BASIS FOR GENERIC SITE SELECTION

Three generic sites have been selected and their characteristics defined. The object of the generic site descriptions is to enable long term stability assessments and evaluations to be made of various cover and containment structure options. These options are representative of either existing structures or covers, or of alternatives that have been proposed as potentially advantageous for long term stability. A range of site conditions and characteristics have been selected to permit the evaluation of a broader variety of conditions.

The generic sites should not be considered to be entirely representative of any existing or future tailings deposit. They serve to evaluate the methodology and results of long term stability analyses, using representative conditions, and do not necessarily reflect the conditions at any existing site. Existing impoundments differ in their details of site layout and characteristics, and their final reclamation and abandonment preparation may differ entirely from any of the alternatives evaluated herein.

II.1.2 ONTARIO SITE

The generic tailings site for the Elliot Lake area has been placed in an existing steep walled, rock rimmed, lake basin. Characteristics of the various components of the impoundment have generally been drawn from the Quirke basin. However, as many of these components are similar to the other impoundments in the area, certain generalizations have been made in order to better represent a site typical of the Elliot Lake area. For convenience, the generic site has been entitled Structure Lake.

II.1.3 SASKATCHEWAN SITES

Because of the variation in the ore types as well as the tailings placement methods used in Saskatchewan, two generic sites have been selected.

A generic wet tailings site has been defined which contains many of the characteristics typical of the tailings deposits associated with lower grade Saskatchewan ore deposits. These tailings have low nickel and arsenic contents, and have been placed by mass discharge behind embankments of more traditional design. This generic site has been entitled W.T. (wet tailings) site.

A generic semidry tailings site has been defined which is more representative of the managed layered tailings deposit being formed at Key Lake. The tailings are derived from higher grade ore deposits and contains considerably greater fractions of radiological waste products as well as other toxic elements such as nickel and arsenic. This generic site has been entitled S.D. (semi-dry) site.

II.2.0 TYPICAL ONTARIO SITE

II.2.1 IMPOUNDMENT LAYOUT

The Structure Lake Tailings Management Area is shown in plan on Figure II.2.1-1. The Structure Lake tailings impoundment is situated in a glaciated valley, nearly continuously rimmed by bedrock. The bedrock consists of the Bruce, Espanola and Mississauga Formations. The tailings are generally 33 m in thickness and are generally underlain by thin, discontinuous deposits of till and peat. At the southern outlet to the basin, an extensive deposit of glaciofluvial material underlies the site. Beneath Dam B, the thickness of this glaciofluvial unit is approximately 10 m.

The Structure Lake tailings impoundment covers 160 ha and contains approximately 35 million tonnes of tailings. The impoundment is surrounded by bedrock ridges except for its northerly and southerly extent where Dams A and B are situated, respectively. Dam A is approximately 20 m high and consists of a zoned embankment with a glacial till thick core. Dam B is 15 m high and is a homogeneous dam comprised of waste rock. Located on the east rock abutment of Dam B is an emergency spillway designed to pass flows associated with the Probable Maximum Precipitation event.

The freeboard above the tailings surface for each dam is 1.5 m.

II.2.2 ENVIRONMENTAL SETTING

The environmental setting for the Elliot Lake area is described in Section I.2.0 of Technical Memorandum I (TM I).

II.2.3 TAILINGS CHARACTERIZATION

The physical and chemical characteristics of the tailings in the Elliot Lake area are detailed in Section I.3.0 of TM I. For convenience, averages of the physical properties of tailings at the Quirke site are listed in Table II.2.3-1. The variation of the physical properties of the tailings with depth are presented in Figure I.3.A-2, of TM I. These profiles are considered representative of the tailings at Structure Lake.

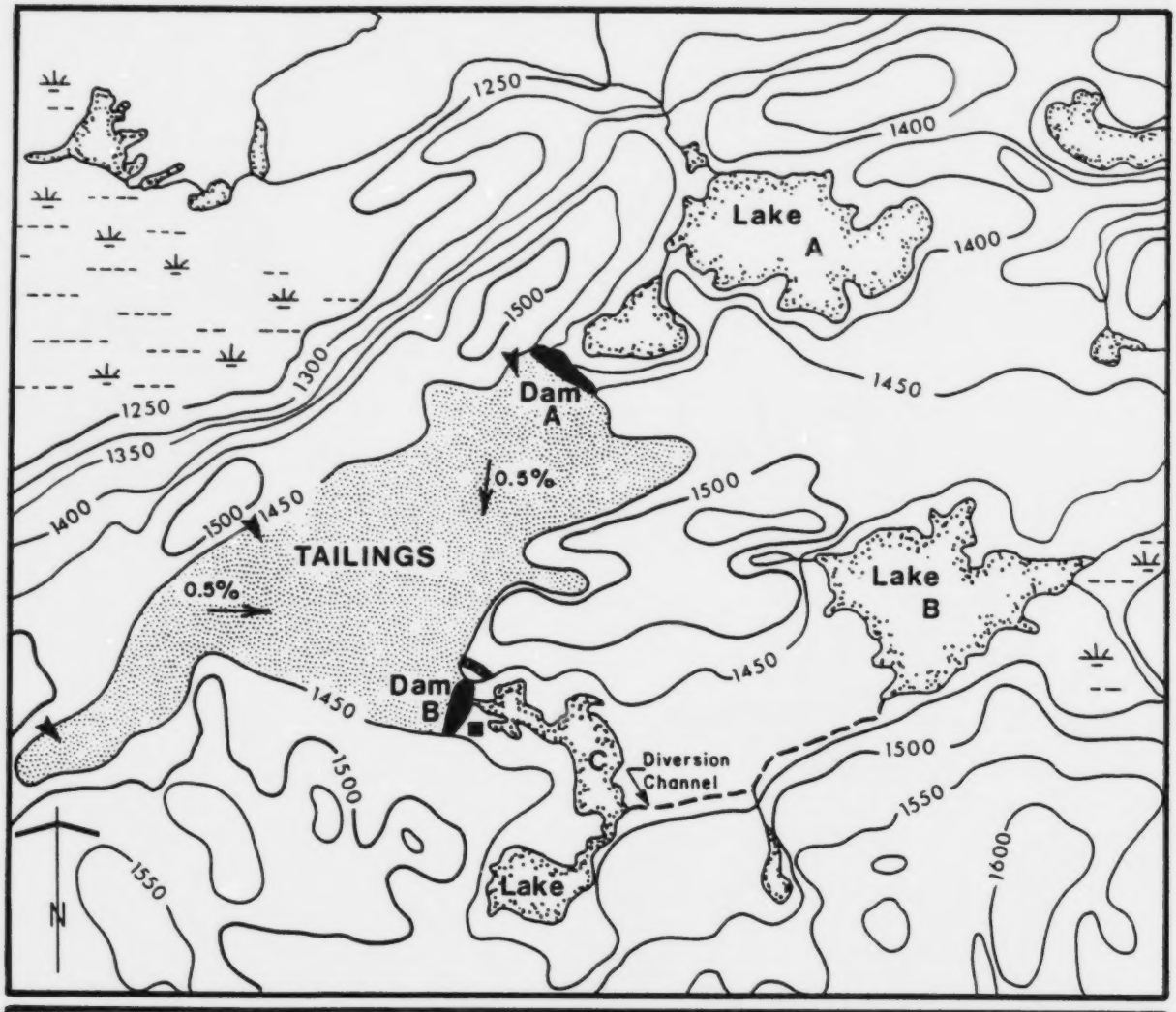
The chemical properties listed in Table I.3.A-3 of TM I, are also considered representative of the tailings at the Structure Lake site and therefore are not repeated herein.

II.2.4 DESCRIPTION OF CONTROL STRUCTURES

II.2.4.1 Embankments

As previously discussed, there are two tailings retention structures at Structure Lake, specifically Dams A and B. Typical cross sections of each dam are shown on Figure II.2.4-1.

Dam A, at its maximum height is 20 m with a crest length of approximately 300 m. The entire dam is founded on bedrock. The core, which is trapezoidal in shape, is comprised of moderate to low permeability glacial till with a



SITE PLAN

STRUCTURE LAKE TAILINGS MANAGEMENT AREA

GENERIC ELLIOT LAKE SITE

Legend

- Diversion Channel
- Discharge Location
- Spillway
- Treatment Plant
- Dam
- 0.5% Direction & Degree of Surface Slope

Scale 1:25,000
Contour Interval - 50'
Contours In Feet A.S.L.

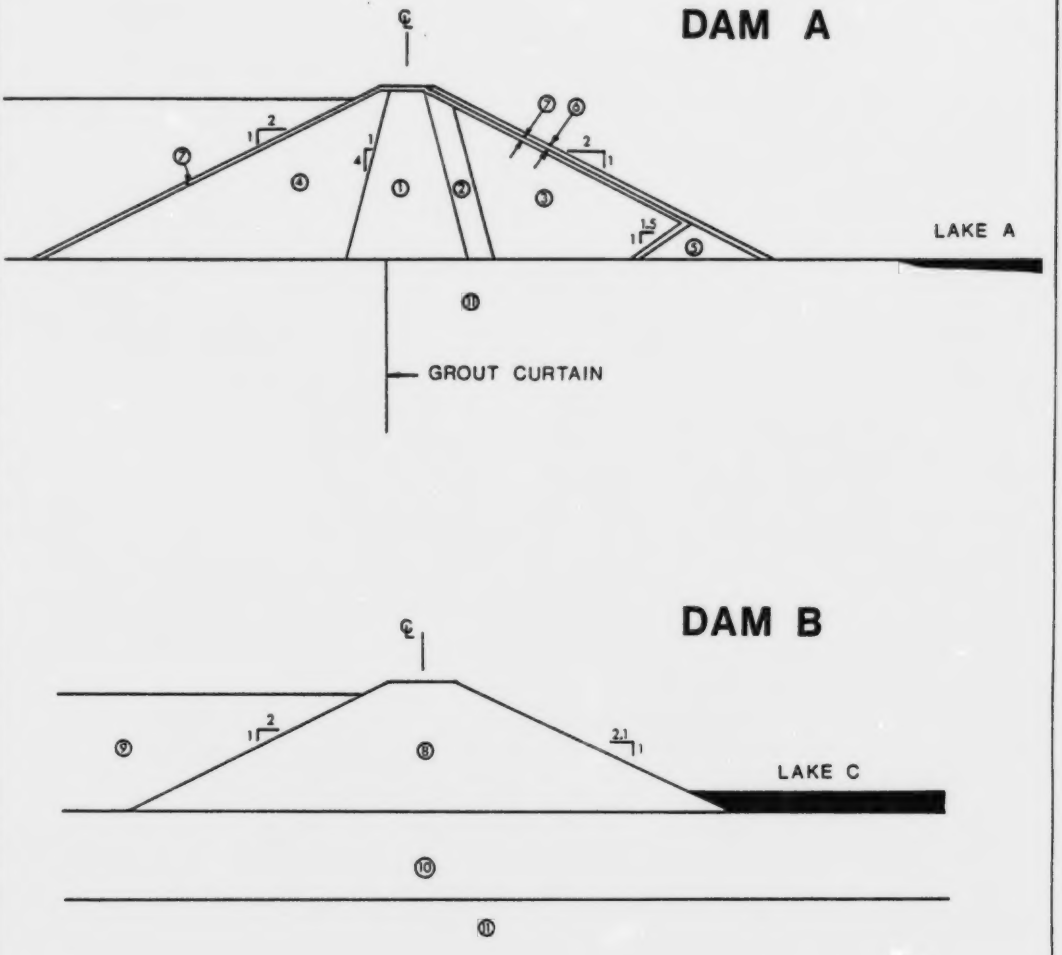
FIGURE II.2.1-1

TABLE II.2.3-1

PHYSICAL PROPERTIES OF STRUCTURE LAKE TAILINGS

PHYSICAL PROPERTIES		COARSE TAILINGS (SANDS)	FINE TAILINGS (SLIMES)
GRADATION (MIT) (% by weight)	GRAVEL	0-5%	0%
	SAND	85-90%	0-20%
	SILT	1-15%	80-85%
	CLAY	0-4%	0-15%
SPECIFIC GRAVITY		2.77	2.81
VOID RATIO		0.7-0.9	1.3-1.7
DRY DENSITY (Kg/m^3)		1500-1700	1100-1300
IN SITU WATER CONTENT		27%	50%
COMPACTION CHARACTERISTICS (STANDARD PROCTOR) Water Content		12%	N/A
Dry unit weight		16.65 kN/m^3	N/A
EFFECTIVE SHEAR STRENGTH Angle of Internal Friction		30.5-41 degrees	36-46 degrees
Cohesion		0 kPa	0 kPa
HYDRAULIC CONDUCTIVITY (m/s) (for the above void ratios)		10^{-5} to $4x10^{-6}$	10^{-7} to 10^{-8}
CONSOLIDATION CHARACTERISTICS Compression Index		0.05-0.1	0.25-0.45
SURFACE LOAD BEARING CHARACTERISTICS		mostly trafficable	not trafficable except when frozen

After Golder Associates Ltd., 1982



TYPICAL CROSS SECTION
DAMS A & B
GENERIC ELLIOT LAKE SITE

Legend

① CORE-GLACIAL TILL
② FILTER-PROCESSED SAND
③ DOWNSTREAM SHELL-SAND AND GRAVEL
④ UPSTREAM SHELL-TAILINGS SAND
⑤ DRAIN-PROCESSED GRAVEL
⑥ EROSION PROTECTION-COBBLES
⑦ BEDDING/EROSION PROTECTION-SELECT SAND AND GRAVEL
⑧ WASTE ROCK
⑨ TAILINGS
⑩ OVERBURDEN/GLACIOFLUVIAL SAND AND GRAVEL
⑪ BEDROCK

0 10 20
m

FIGURE II. 2.4-1

top width of about 5 m and a bottom width of up to 15 m. The side slopes of the core are 1H:4V (1 horizontal to 4 vertical). The glacial till used to construct the core may be classified as a silty sand with some gravel (Figure II.2.4-2). Typical geotechnical properties of the till material are given in Table II.2.4-1.

The downstream shell and filter materials within Dam A are constructed of glaciofluvial sands and gravels. The gradation specifications of these materials are shown on Figures II.2.4-2 and II.2.4-3. Details of the principal granular zones are described below.

A 3 m wide filter zone is provided adjacent to the downstream face of the till core to prevent internal erosion or piping of the embankment. The core and filter zones are supported by upstream and downstream shells of compacted granular material.

The downstream shell comprises environmentally "clean" (free of radionuclides) pit run sand and gravel. The upstream shell is constructed of tailings sand.

A toe drain is included, which consists of processed gravel separated from the downstream shell material by a 0.6 m thick select filter zone of coarse sand and gravel.

Cobble and boulder erosion protection is provided for the downstream slopes. The upstream tailings shell slope was blanketed with sand and gravel as short-term erosion protection, before tailings were deposited against it.

Dam B is 15 m high and has a crest length of approximately 230 m. Unlike Dam A, Dam B is an unengineered, homogeneous structure founded on 10 m of glaciofluvial sands and gravels. The dam is constructed with minus 150 mm crushed waste rock and has downstream side slopes of approximately 2.1H:1V. Estimated physical properties of the waste rock are given in Table II.2.4-1.

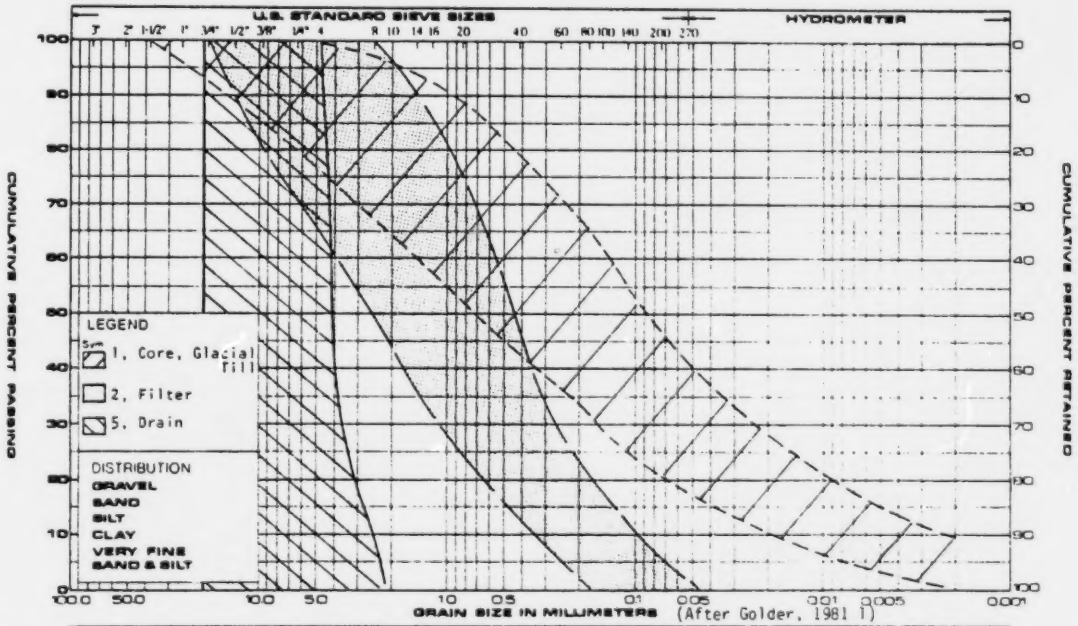
Due to the inherent permeability of Dam B, no underdrains were incorporated into the structure.

II.2.4.2 Liners

Natural geological materials have been used in place of constructed liners in the design of both Dam A and Dam B. In the case of Dam A, the foundation material and natural liner consist of bedrock. Based on packer test results, the upper 6 m of the bedrock demonstrates permeabilities that range between 10^{-5} and 10^{-8} m/s, while the permeability of the rock at depths greater than 6 m is consistently in the order of 10^{-8} m/s.

As previously discussed, Dam B is situated on 10 m of glacial sands and gravels. The permeability of this material was found to be in the order of 3×10^{-5} m/s.

PARTICLE SIZE DISTRIBUTION


U.S. STANDARD SIEVE SIZES
3" 2" 1-1/2" 1" 3/4" 1/2" 3/8" 1/4" 4 8 10 14 16 20 40 60 80 100 140 200 270
HYDROMETER
CUMULATIVE PERCENT PASSING
CUMULATIVE PERCENT RETAINED
100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100
LEGEND
5m
1, Core, Glacial Till
2, Filter
5, Drain
DISTRIBUTION
GRAVEL
SAND
SILT
CLAY
VERY FINE SAND & SILT
1000 500 100 50 10 05 01 005 001 0005 0001
GRAIN SIZE IN MILLIMETERS
(After Golder, 1981 1)

UNIFIED	GRAVEL		COARSE	MEDIUM	FINE		SILT & CLAY					
			SAND									
MIT	STONES	GRAVEL	COARSE	MEDIUM	FINE		COARSE	MEDIUM	FINE		CLAY	
			SAND				SILT					
US BUREAU	GRAVEL		COARSE	MED	FINE	V FINE	SILT				CLAY	
			SAND									

JOB NAME National Uranium Tailings Program JOB NO. 86-1 & 2

REMARKS Construction Materials Specifications FIGURE

CONSTRUCTION MATERIALS SPECIFICATIONS OF CORE, FILTER AND DRAIN
(GENERIC ELLIOT LAKE SITE)

FIGURE II.2.4-2

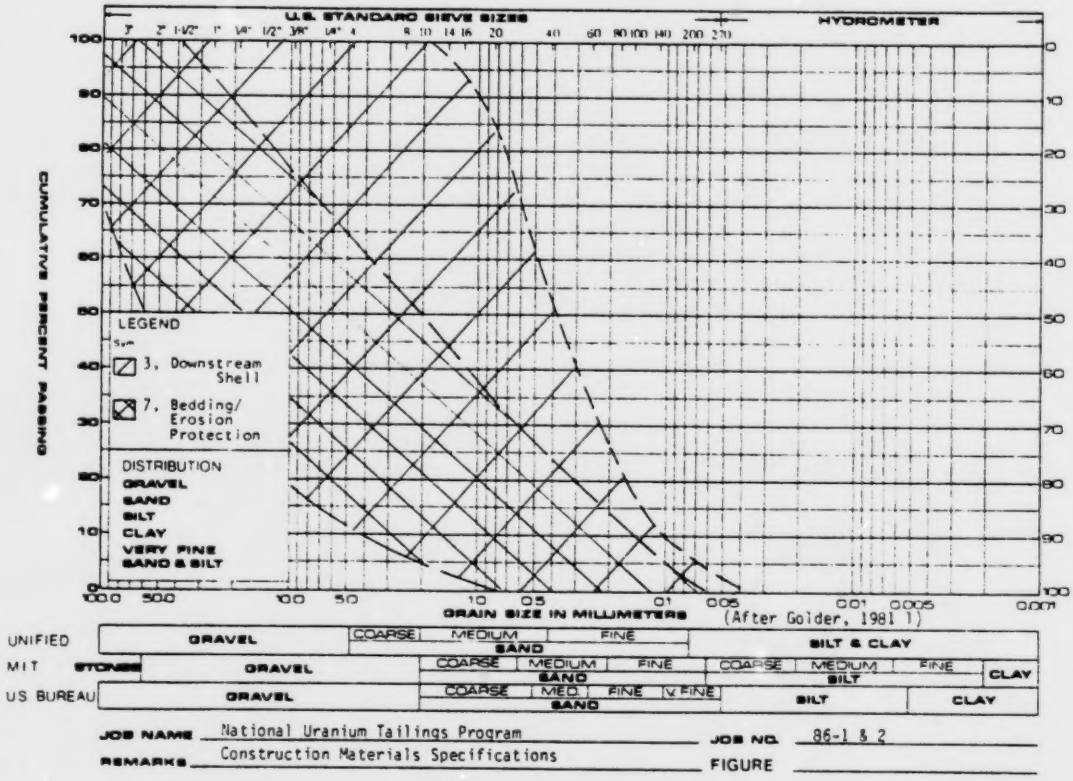
TABLE II.2.4-1

PHYSICAL PROPERTIES OF LOCAL CONSTRUCTION MATERIALS AT STRUCTURE LAKE

PHYSICAL PROPERTIES	TILL	SAND AND GRAVEL	COMPACTED SAND TAILINGS	ROCKFILL
IN SITU WATER CONTENT	8-11%	4-5%	5-25%	N/A
ATTERBERG LIMITS				
Liquid Limit	15-19%	N/A	N/A	N/A
Plasticity Index	2-3%	N/A	N/A	N/A
COMPACTION CHARACTERISTICS				
(STANDARD PROCTOR) Water Content	6-10%	6-13%	12%	N/A
Average dry unit weight	20.6 kN/m^3	18.1 kN/m^3	16.7 kN/m^3	N/A
EFFECTIVE SHEAR STRENGTH				
Angle of Internal Friction	37-40 deg	35-40 deg	36-41 deg	40-45 deg
Avg Angle of Internal Friction	38 deg	35 deg	36 deg	40 deg
Cohesion	0 kPa	0 kPa	0 kPa	0 kPa
TOTAL UNIT WEIGHT (kN/m^3)	22.6	19.6	18.9	19.6
DYNAMIC STRENGTH Kc=1 (cyclic stress for failure at 6 cycles)	0.35	0.36	N/A	N/A
HYDRAULIC CONDUCTIVITY (m/s)				
Compacted	10^{-6} to $4x10^{-10}$	N/A	N/A	10^{-3}
In-situ	10^{-5} to 10^{-7}	10^{-4} to 10^{-5}	10^{-4} to 10^{-6}	N/A

(After Reades et al, 1982, & H.Q. Golder and Associates Ltd., 1978c,1980a & Golder Associates Ltd., 1981l)

PARTICLE SIZE DISTRIBUTION



CONSTRUCTION MATERIALS SPECIFICATIONS, DOWNSTREAM SHELL AND BEDDING/EROSION PROTECTION, GENERIC ELLIOT LAKE SITE

FIGURE II.2.4-3

II.2.4.3 Cover

The Structure Lake Tailings Management Area has been abandoned in a method typical of other Elliot Lake sites. The surface of the tailings deposit has been sloped with tailings in a manner that ensures surface runoff within the tailings impoundment drains towards Dam B. The surface gradient of the tailings is 0.5%. Seepage from Dam B and overflow from the spillway is treated with lime and barium chloride at the treatment plant at the head of Lake C prior to discharge to the Serpent River system.

It is assumed for the generic case that the state of the art of pyrite removal had advanced to a stage where it was economic and pyrite free tailings had been used for the upper 1 m of tailings. The validity of this assumption depends on future technological developments.

Subsequent to the placement of the pyrite-free tailings, the total tailings area had been revegetated.

At the time of abandonment the use of a soil cover over the tailings had been considered in lieu of the above option. However, due to the massive volumes of borrow material required to cover the impoundment area, this option was not considered to be feasible.

II.2.4.4 Diversion Works

Diversion works incorporated into the design of the Structure Lake tailings impoundment consist of a channel which was constructed to divert water from Lake C towards B Lake. The diversion channel was excavated through both overburden and bedrock. The dimensions of the trapezoidal channel are as follows:

- Bottom width = 1.8 m
- Side slopes (rock cut) = 1H:2V
  (overburden) = 2H:1V
- Slope = 0.5%
- Total length = 500 m

Precipitation falling on the impoundment and surrounding catchment flow towards the pond area where it is stored and routed over a concrete spillway for discharge.

II.2.4.5 Seepage Control

Seepage control at the Structure Lake tailings impoundment consists of the grout curtain located beneath Dam A. The grout curtain was extended to a maximum depth of 20 m beneath the highest section of the dam. Reports suggest the mass permeability of the rock after grouting was 10^{-7} m/s. The grout curtain was comprised of a single line of primary grout holes on a 6.1 m spacing. In zones where the grout take was appreciable, secondary and/or tertiary holes were drilled at 3 m and 1.5 m spacings, respectively.

The basic grout ingredients were sulphate-resistant Portland cement, bentonite and water. Typically four to 12 percent by weight of bentonite to

cement was used. Grout mixes generally ranged from 3:1 to 0.5:1 (water:cement ratio).

II.2.4.6 Water Storage and Quality Control

With the present configuration of the tailings impoundment, all surface runoff is diverted to the outlet of the basin at Dam B. As previously mentioned, the overflow from the tailings area and seepage through Dam B is treated with lime and barium chloride at the head of Lake C. The quality of water discharging from Lake C for the most part meets Provincial surface water quality objectives. However, since abandonment the quantity of materials required to neutralize the effluent has steadily increased over the years. The seepage quantities through and below Dam B is estimated to be 2.1 L/s.

At Dam A, based on an estimated quantity of seepage of 0.04 L/s through the dam, no treatment facilities have been required to date.

II.2.4.7 Storm and Flood Flows

II.2.4.7.1 Objective

The objective of this exercise was to route a storm event through the generic tailings area at Elliot Lake. The storms under consideration included a variety of events with different return periods, and the Timmins Storm of 1961. The pond has certain generic characteristics as described below.

II.2.4.7.2 Assumptions

The watershed used in this generic assessment, as shown on Figure II.2.1-1, was selected to provide a pond that would meet capacity requirements of a tailings pond in the Elliot Lake area. The pond is contained by Dams A and B, with a spillway in the vicinity of Dam B. The outflow from Lake C is to be diverted in a channel away from the pond towards Lake B.

The watershed contributing to the pond has an area of approximately 360 hectares, following the construction of Dam B. This watershed comprises 160 ha of tailings surface and 200 ha of forest. The local terrain consists mainly of rock knobs and has moderate relief. Runoff coefficients of 0.7 and 1.0 have been assumed for the forested terrain and tailings pond, respectively.

It has been estimated from topographic maps that the average ground slope around the perimeter of the pond is 15%. The perimeter of the pond, at an elevation of 1450 feet (442 m) a.s.l., was measured to be approximately 7,625 m. The use of perimeter ditches to divert surface flows from adjacent catchment areas was considered at the time of abandonment. It was concluded that the potential for blockage of such ditches due to vegetation growth and debris blockage was very high and consequently that drainage would be routed over the tailings impoundment.

The freeboard of the dams was assumed to be 1.5 metres, of which 1.2 m may be used for interim storage. These dimensions are considered typical for

Elliot Lake tailings dams. The pond is assumed to be empty at the beginning of the storm, i.e. there is no flow over the weir at time zero.

A selection of precipitation events were considered. Based on the earlier work of other consultants (MacLaren & Golder, 1980) an event length of 12 hours was used. Table II.2.4-2 gives the dimensions of the storms used.

The Regional Storm at Elliot Lake is defined as the Timmins Storm. PMP is used to denote the Probable Maximum Precipitation event, which usually causes the Probable Maximum Flood (PMF). For the purposes of this analysis the rainfall for each storm was distributed according to a Soil Conservation Service (SCS) Type II distribution (USDA, 1972) which had been compressed into the 12 hour duration.

II.2.4.7.3 Calculation Method

Precipitation distribution was calculated according to a compressed SCS Type II distribution. The flood routing was calculated using a storage indication method (Viessman et al, 1977). This technique is also known as the Modified Puls Method.

Calculations of the time of concentration for this watershed gave values of approximately 10 minutes. Because this value is well inside the time step of one hour used in the routing, it was assumed that the precipitation that fell during a time step would be the inflow for that time step.

Preliminary calculations showed that the largest storm under consideration (424.2 mm in 12 hours) would only fill the pond to a depth of approximately 0.8 m. Therefore, the aim of the analysis moved from "determining a minimum spillway width to carry a storm" toward "characterizing the outflow for a typical spillway". A typical spillway width of 5 m was selected for these calculations. The dimension of width is measured perpendicular to the flow of the water.

The five storms listed in Table II.2.4-2 were routed through the pond and over a spillway 5 m wide.

II.2.4.7.4 Results

Table II.2.4-3 lists the peak outflow rate and volume of ponded water for each of the storms investigated. The depth of water at the 5 m wide weir is also listed.

Table II.2.4-3 shows that the greater depth of water at the weir is approximately 0.8m , which is 67 % of the available freeboard. This depth also represents the pond at 33% of available storage.

A peak outflow rate of 583 L/s has been calculated for a 5 m weir and a 424 mm storm. Smaller storms have smaller peak outflow rates.

II.2.4.7.5 Conclusions

These results indicate that the pond, as assumed, can hold any of the design storms without overtopping, regardless of the size of the weir,

TABLE II.2.4-2

PRECIPITATION DATA FOR STRUCTURE LAKE, ONTARIO

EVENT LENGTH (HOURS)	RETURN PERIOD (YEARS)	DEPTH (mm)
12	10	73.2
12	25	88.4
12	100	158.5
12	REGIONAL STORM	193
12	PMP*	424.2

*Probable Maximum Precipitation Event

TABLE II.2.4-3

FLOOD ROUTING RESULTS, GENERIC ELLIOT LAKE SITE

DEPTH OF STORM (mm)	PEAK OUTFLOW RATE (L/s)	STORAGE AT TIME OF PEAK OUTFLOW (000's of m^3)	MAXIMUM POND DEPTH (m)
73.2	43	220	0.14
88.4	56	260	0.17
158.5	136	470	0.30
193	186	580	0.36
424.2	583	1257	0.80

given that the pond has 0.8 m of useable freeboard at the start of the storm.

The calculations also indicate that the pond could also hold any two of the design storms, concurrently, except two PMP's, if it was empty at the start of the sequence of storms. The superior capacity of the pond is related to the high proportion of pond within the watershed (approximately 44%).

The size (width) of the weir installed at abandonment was made large to minimize the depth of water stored on the tailings during a flood event. Periodic flooding of a portion of the tailings impoundment surface is expected. Such flooding may result in vegetative cover loss in the vicinity of the weir (most frequently flooded areas).

II.2.5 TAILINGS DEPOSIT CHARACTERIZATION

Prior to treatment, the tailings slurry from the Structure Lake Mill had a pH of 2 to 2.5. The tailings slurry was subsequently neutralized with limestone to a pH of 3.5 and lime to a pH of 10 to 11, similar to the Quirke neutralization process. The neutralized tailings were then pumped to the Structure Lake tailings impoundment for disposal.

Tailings were discharged into the impoundment from the north side of the basin. As shown on Figure II.2.1-1, there were three separate discharge locations used over the life of the site. Tailings were discharged from only one location at a time. By using three separate discharge points the tailings impoundment was constructed in three large cells.

The coarse sands are typically along the north side of the impoundment and the slimes or silt size materials are generally to the south. The impoundment surface supports traffic at all times over the well drained sand zones. Slimes zones can be accessed by vehicles only in the winter when the tailings have frozen.

Throughout the active life of the basin the headpond abutted Dam B. Upon abandonment the headpond was drained and the concrete spillway weir installed.

II.2.6 ALTERNATIVE COVERS

The following section describes the various cover types that were considered prior to the abandonment of the Structure Lake Tailings Management Area. The advantages and disadvantages of each option are not discussed herein, but by others in Technical Memorandum V (TM V).

Essentially three alternative cover types were reviewed prior to abandonment, these include no cover at all, application of a thin cover or placement of a thick cover. Within each of these alternatives there were three material types that were reviewed, details of each approach are summarized in Table II.2.6-1 described below.

TABLE II.2.6-1

SUMMARY OF ALTERNATIVE COVERS CONSIDERED

A. No Cover

(i) No action; allow self stabilization
(ii) Contour and direct revegetation
(iii) 1 m pyrite free tailings plus contouring and revegetation

B. Thin Covers (about 0.6 m thickness)

(i) Contour, place 0.6 m soil cover and revegetation
(ii) Contour, place 0.6 m crushed rock
(iii) Extensively re-contour, upgrade dams and install 0.6 m water cover

C. Thick Covers (about 3 m thick)

(i) Homogeneous cover material
(ii) Layered cover. 1 m sand over 1 m till over 1 m sand and gravel
(iii) Extensively re-contour, upgrade dams and install 3 m of water cover

---

A. No Cover

(i) No Action: As the name implies no reclamation measures would be undertaken to promote revegetation or stabilization of the surface. Once the headpond had been drained, the impoundment would be left to self-stabilize.

(ii) Contour & Direct Vegetation: After the headpond had been drained the tailings surface would be contoured and terraced at an overall slope of about 0.5% from the north to the south of the impoundment. Once this was completed, a revegetation program would be undertaken to seed directly onto this surface.

Construction on the tailings should be undertaken using wide tracked equipment. Access onto the slimes zones of the impoundment will require improved drainage installed during winter when access is possible. In areas of very poor trafficability which cannot be adequately drained it will be necessary to place a sufficient thickness of cover material during winter to allow traffic access in the summer.

(iii) Contour with Pyrite Free Tailings & Direct Vegetation: In this approach a 1 m thick lift of pyrite free tailings would be hydraulically deposited over the entire impoundment after the headpond had been lowered. This material would then be contoured, terraced and revegetated in a similar manner to the above option.

Construction on these tailings should also be carried out using wide tracked equipment, with drainage and or cover material placement on the slimes zones during winter, as required.

B. Thin Cover

(i) Contour, Soil Cover & Vegetation: After the tailings surface has been contoured and terraced in a similar manner described above, a 0.6 m soil cover comprised of locally available silty sand till would be placed. Properties of this material are described in TM I. Once the soil cover has been placed the surface would be revegetated.

As in the case of the other options, construction equipment should be equipped with wide tracks, and some winter placement may be necessary.

(ii) Contour & Waste Rock: A 0.6 m layer of coarse rock gravel would be placed overtop of the contoured tailings surface. The coarse gravel rock, as described in TM I, would be comprised of well graded, competent minus 250 mm material. This rock would be obtained in part from mine waste rock and from local quarried rock.

(iii) Water: The third approach within the thin cover's category was flooding of the tailings impoundment with 0.6 m of water. The tailings surface would have to be extensively recontoured by dredging and other means to achieve a flat tailings surface. Since the crests of Dams A and B were originally designed to be 1.5 m above the final tailings surface it would be necessary to raise them both accordingly by the downstream method to ensure 1.5 m of freeboard. In addition to

this, supplementary geotechnical analyses and dam improvement would have to be undertaken to ensure their stability as water retaining structures. It is recognized that practical limitations are severe. Nevertheless, it is included for generic evaluation purposes.

C. Thick Cover

(i) Homogeneous Cover: Within this option, a 3 m thick cover of silty sand till would be placed directly over the entire tailings surface. The surface would be contoured and terraced in a manner to direct surface runoff towards the spillway at Dam B. The physical properties of the till material are described in TM I. The surface of the cover material would be revegetated as mentioned earlier.

(ii) Layered Cover: Due to the lack of low permeability material in the vicinity of the tailings impoundment, a layered cover was proposed. The cover would be comprised of 1 m of sand and gravel overlying 1 m of till over a 1 m thick layer of sand and gravel. The lower 1 m of sand and gravel would be used as bedding material for the till. The properties of these materials are also described in TM I.

The placement of these materials must be carried out using wide tracked equipment, with appropriate drainage preparation and winter construction as required.

(iii) Water Cover: The final option entails flooding the impoundment with 2 m of water. As in the case of the previous thin water cover option, the tailings would have to be re-contoured and Dams A and B would have to be raised to allow for a 1.5 m freeboard. In keeping with the recognized practice in the area the dams would be raised in a downstream fashion.

Although soil amendments (fertilizers, neutralizing agents) may vary for each of the alternative cover materials, as described above, (unaltered tailings, pyrite-free tailings, silty sand till, sand and gravel) a basic type of herbaceous seeds mixture will be established on all of the cover materials. The prime component of the seeds mixture will be a legume, birdsfoot trefoil. Additional components will be one or more of various grass species selected from, for example, creeping red fescue, tall fescue, Kentucky bluegrass, bentgrass and perennial rye grass.

A seeds mixture would be seeded in late May to the end of June. Given average climatic conditions, an herbaceous ground cover of approximately 75% per unit area should be achieved by July/August of the following year. With correct agronomic inputs, such a vegetation cover should be considered permanent and self-sustaining but with time, (>10 years) the type and proportion of species will change as natural plant succession processes occur and indigenous shrub and tree species invade seeded locations. Whether the changing vegetation composition will approach the typical forest types of the Elliot Lake region or will stabilize as a scrub type vegetation apparent today is unknown.

II.3.0 TYPICAL SASKATCHEWAN WET TAILINGS SITE

II.3.1 IMPOUNDMENT LAYOUT

The wet tailings (W.T.) site is located within a naturally occurring depression gouged out of the basement rock. The mill site was located approximately 5 km northeast of the tailings impoundment area. A lake is located to the southeast of the tailings area.

The depression has a general northeast to southwest orientation and is rimmed with bedrock on both the east and west flanks (Figure II.3.1-1). Overburden on the site consists of till of varying thickness, ranging from a thin veneer less than a metre in thickness to a maximum of 7 m. The till matrix consists mainly of silt and sand although it contains gravel and cobbles with numerous boulders. Although some topsoil was evident on the site, a thin cover (0.5 to 2 m) of peat predominates.

A containment dam has been constructed to enclose the southerly portion of the depression providing an impoundment area of 75 ha with a maximum depth of deposition of 20 m. Construction of the dam used the downstream method and proceeded on an annual basis with the maximum height of construction dependent upon the next year's storage requirements. A seepage collection system consisting of a filter blanket and interception trench has been constructed to capture seepage from the tailings impoundment area and drain it to the treatment facilities located at the toe of the containment dam.

The tailings were piped from the mill to the tailings area where it was alternately discharged from the northeast and southwest. A barge pump was used to decant liquids. The decant was pumped through an overland pipeline to the treatment ponds. Here the supernatant was treated with barium chloride and clarified in a settling pond prior to discharge to the environment. The treatment ponds are constructed of compacted till and lined with a synthetic membrane.

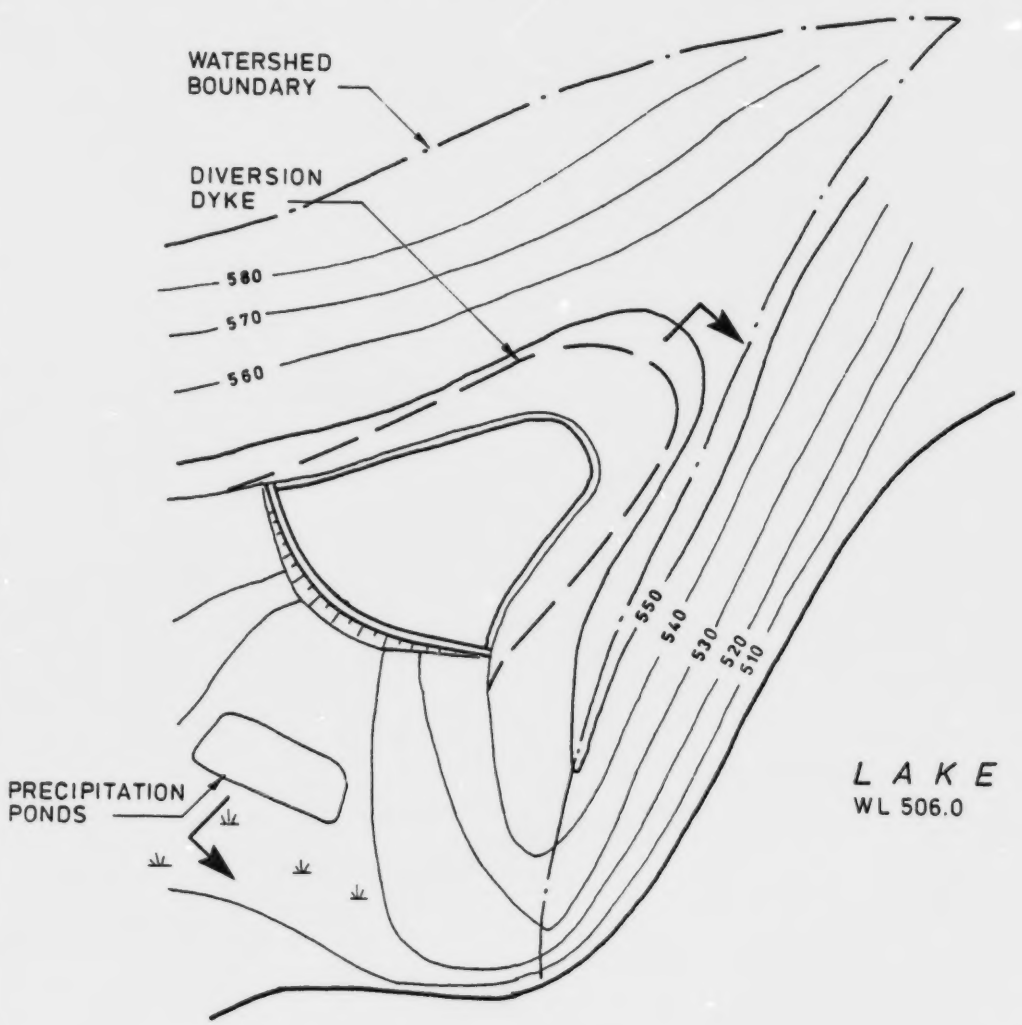
II.3.2 ENVIRONMENTAL SETTING

II.3.2.1 Meteorological Data

The climate in this study area is characterized by a short cool summer boreal forest climate. The mean annual temperature at the site is approximately -4.7 degrees C, with mean daily temperatures ranging from -28 degrees C in January to +16 degrees C in July. Extreme temperatures range from -50 degrees C to +35 degrees C. The average freezing index for the area is 3260 degrees C-days.

The mean annual precipitation amounts to 402 mm, with approximately 75 percent of the precipitation occurring between the months of May and October. The greatest precipitation measured in a 24 hour period was 75 mm over an 11 year period of measurement. A summary of hydrologic events is given in Table II.3.2-1, while precipitation, temperature and evaporation data are included in Figure II.3.2-1 to -3 and in Table II.3.2-2.

Wind velocities are generally uniformly distributed. The mean wind velocity is approximately 10 km per hour with a minor predominance of



SITE PLAN

W.T. (WET TAILINGS) SITE LAYOUT

(SASKATCHEWAN GENERIC WET TAILINGS SITE)

FIGURE 11.3.1-1

TABLE II.3.2-1

SUMMARY OF HYDROLOGIC DATA, NORTHERN SASKATCHEWAN

Average annual precipitation	414 mm
24 hr rainfall, 2 year return	37 mm
24 hr rainfall, 5 year return	50 mm
24 hr rainfall, 10 year return	62 mm
24 hr rainfall, 25 year return	75 mm
Probable maximum precipitation in 24 hr	300 mm
Ratio 6 hr: 24 hr rainfall	0.6
Ratio 48 hr: 24 hr rainfall	1.2
Ratio 72 hr: 24 hr rainfall	1.3

(from Gray, 1970)

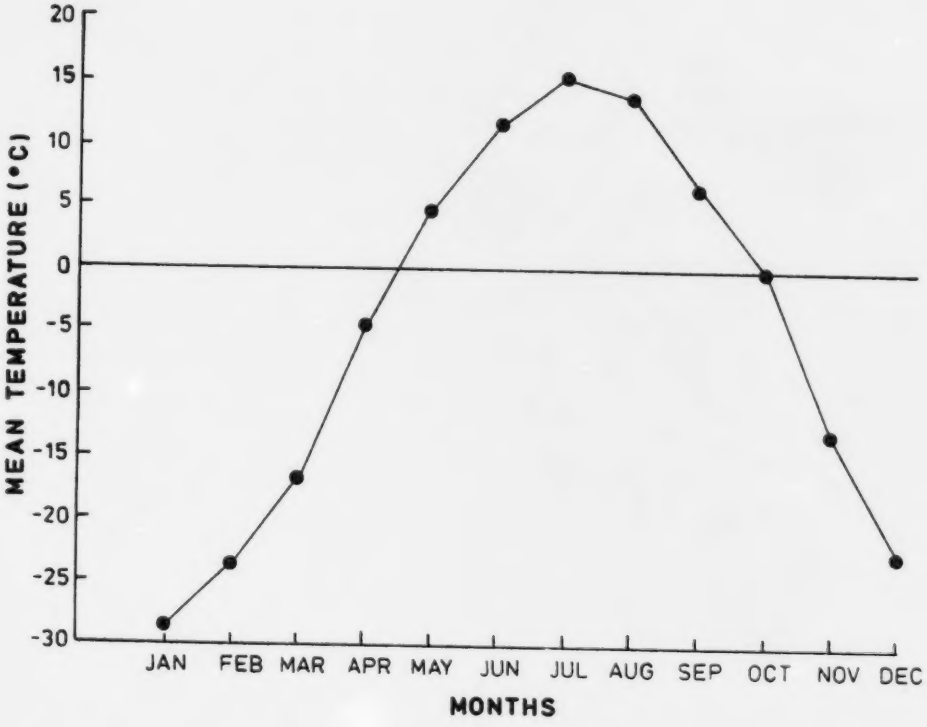
TABLE II.3.2-2

AVERAGE WATER BUDGET CALCULATION
W.T. SITE

MONTH	MEAN TEMP (°C)	ADJ EVT (mm)	MEAN PRECIP. (mm)	NET WATER BALANCE (mm)
January	-28.4	0.0	17.9	17.98
February	-23.5	0.0	13.7	13.7
March	-16.8	0.0	18.1	18.1
April	-4.4	0.0	19.1	19.1
May	4.7	48.7	27.3	-21.4
June	11.8	105.3	50.9	-54.4
July	15.5	126.7	64.0	-62.7
August	13.8	102.7	55.8	-46.9
September	6.7	48.2	51.0	2.8
October	-0.1	0.0	33.2	33.2
November	-13.0	0.0	27.4	27.4
December	-22.6	0.0	23.4	23.4
TOTAL	-4.7	431.7	401.8	-29.9

TOTAL PRECIPITATION	402 mm
POTENTIAL EVAPOTRANSPIRATION	432 mm
NET WATER BALANCE	-30 mm

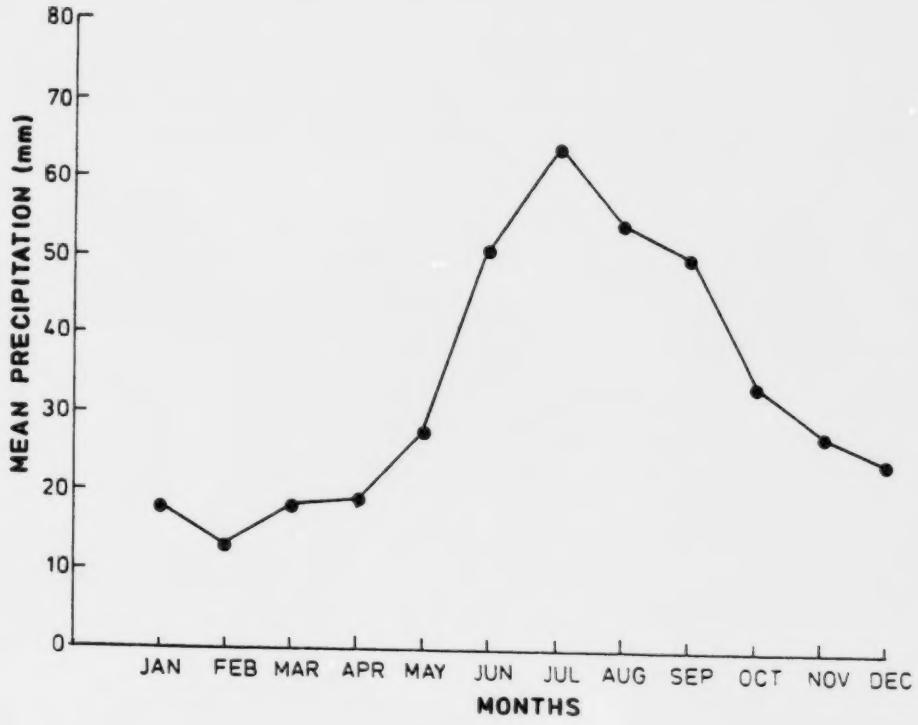
(from Clifton Associates Ltd., 1985)



(From Table I.2.B-3 Rabbit Lake)

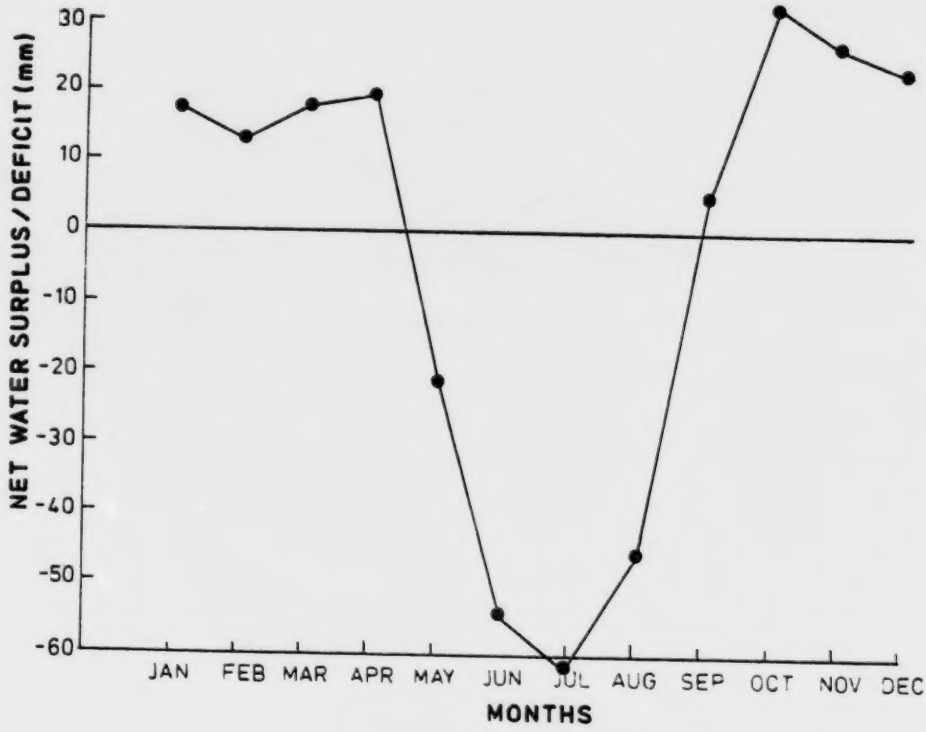
MONTHLY TEMPERATURES, SASKATCHEWAN GENERIC WET TAILINGS SITE

FIGURE 11.3.2-1



MONTHLY PRECIPITATION, SASKATCHEWAN GENERIC WET TAILINGS SITE

FIGURE II. 3.2-2



WATER BUDGET, SASKATCHEWAN GENERIC WET TAILINGS SITE

FIGURE II.3.2-3

southeasterly and northwesterly winds. The peak hourly wind is estimated to be between 83 and 93 km per hour for the 10 year frequency; 95 to 103 km per hour for the 30 year frequency; and 101 and 119 km per hour for the 100 year frequency.

II.3.2.2 Topography and Geomorphology

The uranium mine is located within the Canadian Shield, a glacially scoured complex of geologically ancient rocks. The oldest rocks are ancient Archean granites which comprise the basement complex. These are more than 2 billion years old. They are overlain and interfolded with a series of Aphebian age (1.7 to 2.0 billion years old) metamorphosed, deformed and recrystallized sediments which were derived from the basement rocks. The Athabasca sandstone formation of Helikian age was laid down on the older rocks approximately 1 billion years ago. The uranium mineralization is usually found near the contact between the Athabasca sandstone and the older rocks or within highly altered Aphebian rocks.

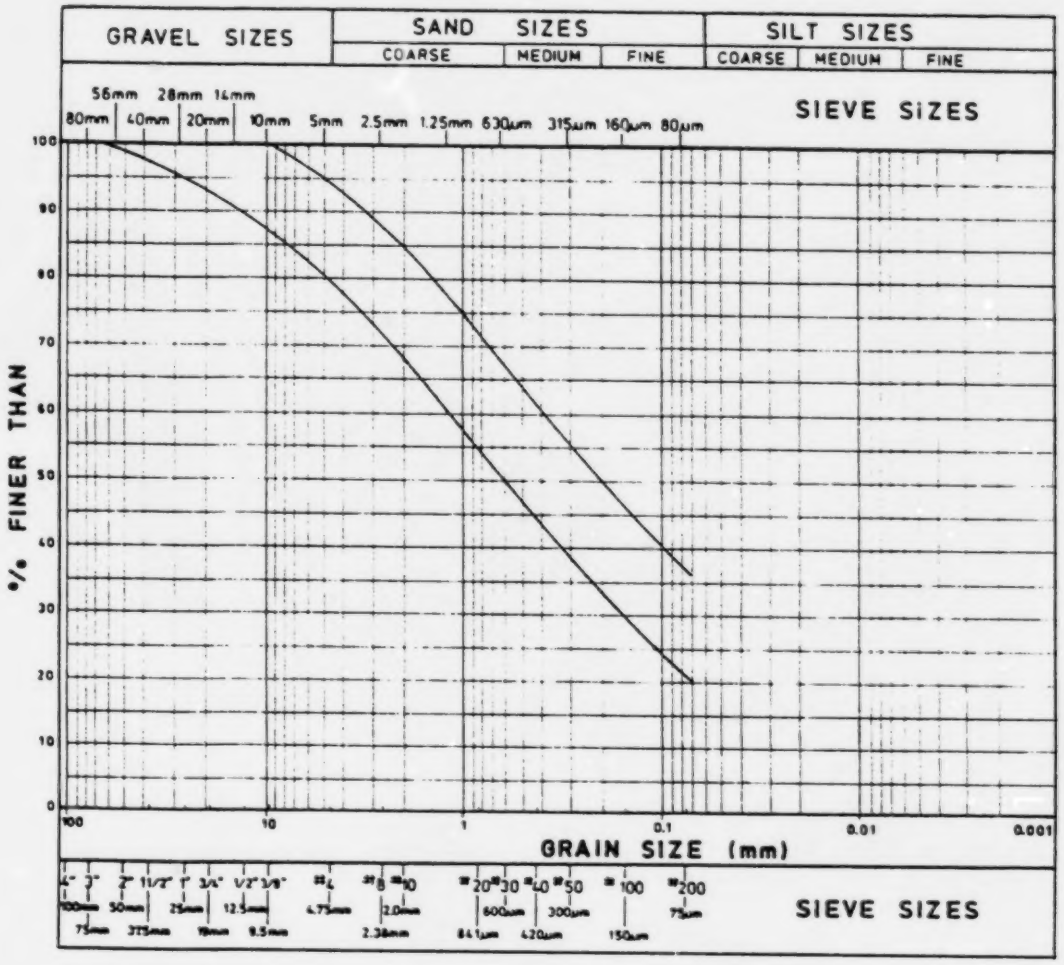
The surface of the Precambrian rock has been extensively scoured by glacial erosion and covered with a thin veneer of glacial and proglacial sediments. Local relief is generally less than 100 m.Glacial sediments are generally thin and comprised of coarse textured glacial silt and outwash sand derived from the Athabasca sandstone. Topographic depressions are often infilled with peat. The entire area is within the zone of discontinuous permafrost and the peat filled depressions often contain ice-rich, permanently frozen soil. The regional drainage is generally poorly integrated and is comprised of many landlocked lakes and bogs. The surface water is generally of very high quality with a very low mineral content, most often with a total dissolved solid content of less than 200 mg/L. The pH of the water varies from about 5.5 to 8.0, but may be as low as 3.0 in stagnant muskeg areas.

Elevated water bodies and peat bogs provide ample recharge for the groundwater systems. Major aquifers include glacial outwash plains comprised primarily of sand; glacial till strata; and fractured bedrock. The drift and fractured bedrock is relatively permeable but the hydraulic conductivity of the bedrock generally decreases with depth. Groundwater quality is generally of very good quality and closely reflects the surface water quality.

II.3.2.3 Geology

Stratigraphy in the impoundment area consists of a variable thickness of silty, sandy till overlying bedrock. A thin covering of peat is evident in low lying areas. Till in the area varies in thickness, ranging from a thin veneer less than a metre in thickness to a maximum of 7 m. It consists predominantly of silty sand and gravel but contains numerous cobbles and boulders. A typical grain size distribution for the till encountered is shown on Figure II.3.2-4. An average insitu permeability of 1×10^{-6} m/s has been measured for the till.

The Athabasca sandstone formation has been stripped from the tailings site, leaving the bedrock surface composed of graphitic and nongraphitic pelitic and subpelitic gneisses, calcareous and quartzofeldspathic gneisses and



TYPICAL TILL GRAIN SIZE DISTRIBUTION, SASKATCHEWAN
GENERIC WET TAILINGS SITE

FIGURE 11.3.2-4

calcsilicate rocks. The bedrock is generally fractured to a depth of up to 25 m resulting in an average measured permeability of $1X\ 10^{-7}$ m/s. Beyond the zone of fractured rock, the permeability decreases to an average value of 1×10^{-8} m/s. Along the flanks of the impoundment area the till overburden thins and there are numerous bedrock outcrops.

II.3.2.4 Groundwater

A single groundwater system exists within the surficial till and the upper fractured bedrock. The groundwater system in the area is shallow, with the water level generally within 2 m of the ground surface. Within the study area, the groundwater system is a reflection of the surface topography, with high water levels associated with ridges and low water levels with depressions. Topographic lows are generally groundwater discharge areas and are therefore occupied by lakes or swamps.

II.3.2.5 Hydrology

The tailings deposit is in a forested bedrock basin which is covered with a thin veneer of till. The contributing watershed has a total area of 270 ha with an average slope of 4%. The longest drainage path is 1700 m. Drainage from the tailings area is towards the nearby lake entering a boggy area before draining to the lake.

II.3.2.6 Groundwater and Surface Water Quality

Groundwater was sampled and analyzed for radionuclides, trace metals and major ions. Table II.3.2-3 shows the mean values for the parameters measured. In general, the groundwater has a mean pH of 6.2.

Baseline surface water quality is shown on Table II.3.2-4.

II.3.3 TAILINGS CHARACTERIZATION

The ore body mined at the W.T. site consists mainly of pitchblende and coffinite with some minor nickel and arsenic content. The most common gangue minerals present are calcite and phyllosilicates. Typical analysis for the ore is shown on Table II.3.3-1.

The W.T. mill utilized an acid leach circuit and solvent extraction system with a countercurrent decantation system to separate the uranium in the leach solution from the tailings solids, followed by ammonia precipitation. The tailings were then neutralized and piped to the tailings impoundment area.

Typical chemical properties of the decant and effluent stream are shown on Table II.3.3-2. The typical chemical properties of tailings pore water are shown on Table II.3.3-3.

The tailings slurry was approximately 40 percent solids by weight. A field investigation of the insitu tailings was conducted to evaluate the geotechnical properties of the tails. Areas predominantly made up of the coarse grained fraction of the tailings and the fine grained tailings or slimes were sampled. Physical properties of the tailings are summarized on

TABLE II.3.2-3

BASELINE GROUNDWATER QUALITY, W.T. SITE

pH	6.2
Cond	350 umho/cm^2
O-PO_4	0.06
TKN	10.0
NH_3	4.00
NO_3	0.075
SO_4	11
Cl	19.2
Ca	22
Na	4.7
Mg	8
K	16
T. Ra^{226}	2.45 pCi/L
U	0.002
Pb^{210}	10.0 pCi/L
Po^{210}	0.3 pCi/L
Th^{226}	0.7 pCi/L
Ag	<0.10
Al	0.20
As	<0.10
B	<0.10
Ba	0.3
Cd	0.05
Cr	0.01
Cu	0.09
F	0.20
Fe	40.0
Hg	0.00013
Mn	1.1
Mo	<0.01
Ni	0.03
Pb	0.10
Se	<0.01
V	0.02
Zn	0.80

Note: pH expressed in standard units; all other parameters in mg/L except where noted.

TABLE II.3.2-4

BASELINE SURFACE WATER QUALITY,
W.T. SITE

pH	6.67
Cond	15.70
O-PO_4	<0.01
T.PO_4	<0.02
TKN	0.15
NO_3	0.04
TDS	30
TSS	1.4
SO_4	3.04
CL	0.51
CO_3	5.3
Ca	2.6
Na	0.83
Mg	0.85
K	2.7
D. Ra^{226}	<0.2 Bq/L
T. Ra^{226}	<0.2 Bq/L
U	0.0003
Pb^{210}	<0.2 Bq/L
Po^{210}	<0.2 Bq/L
Th^{230}	<0.2 Bq/L
Ag	<0.01
Al	0.19
As	<0.01
Ba	<0.1
Bi	<0.2
Cd	<0.005
Co	<0.1
Cr	<0.01
Cu	<0.005
Fe	2.1
Hg	<0.00001
Mn	<0.03
Mo	<0.01
Ni	<0.01
Pb	<0.01
Se	0.02
V	<0.005
Zn	<0.005

Note: pH expressed in standard units; all other parameters in mg/L except where noted.

TABLE II.3.3-1

TYPICAL ORE COMPOSITION, W.T. MINE

Element	(%)
U_3O_8	0.3
ThO_2	n/a
Fe	n/a
S	n/a
Mo	0.002
V	0.02
Ni	0.01
As	0.003
Ra-226	30 Bq/g
PO_4	0.2
CO_2	2-3

TABLE II.3.3-2

CHEMICAL PROPERTIES OF TAILINGS LIQUIDS, W.T. MINE

	DECANT (mg/L)	EFFLUENT (mg/L)
pH	7.8	6.0
Cond	8941 umho/cm^2	1936 umho/cm^2
T.PO_4		0.02
TKN		36.
NH_3		31.
NO_3		1.0
TSS	12.9	3.0
SO_4		1200
CL		24
HCO_3		16
CO_3		1
Ca		82
Na		27
Mg		2277
K		5.0
T. Ra^{226}	11 Bq/L	0.02 Bq/L
U	500	32
Pb^{210}		0.25 Bq/L
Th^{230}	0.14 Bq/L	0.006 Bq/L
Ag	<.004	<0.001
As	4	15
B	0.45	0.06
Ba	0.05	0.12
Cd	<0.003	0.007
Co	0.01	<0.003
Cr	0.02	0.02
Cu	0.02	0.02
F	8.5	0.5
Fe	0.14	0.8
Hg	0.08	0.7
Mn	1.5	0.6
Mo	1.5	0.3
Ni	0.06	0.05
Pb	<0.03	0.03
St	0.07	<0.001
V	<0.01	<0.01
Zn	0.07	0.02

Note: pH expressed in standard units; all other parameters in mg/L except where noted

TABLE II.3.3-3

CHEMICAL PROPERTIES OF TAILINGS PORE WATER, W.T. MINE

	(mg/L)
pH	5.0-8.5
Cond	3700-4950 umho/cm^2
$O\text{-}PO_4$	0.03
TKN	360
NH_3	321
NO_3	5
SO_4	6300
Cl	210
HCO_3	35
CO_3	0
Ca	470
Na	150
Mg	950
K	30
T. Ra^{226}	0.8-18. Bq/L
U	0.3-0.5
Po^{210}	1.5-4.5 Bq/L
Th^{230}	1.6-5.5 Bq/L
As	0.001
B	0.8
Ba	0.1
Cd	0.007
Co	0.15
Cr	0.02
Cu	0.06
F	1.1
Fe	0.25
Hg	<0.0001
Mn	0.4
Ni	0.4
Pb	0.1
V	<0.01
Zn	0.06

Note: pH expressed in standard units; all other parameters in mg/L except where noted

Table II.3.3-4. Typical grain size curves for fine and coarse grained tailings are shown on Figures II.3.3-1 and -2.

II.3.4 DESCRIPTION OF CONTROL STRUCTURES

II.3.4.1 General

The major control structure is a containment dam constructed at the southwest end of the tailings impoundment area. The dam layout and cross section are shown on Figure II.3.1-1 and Figure II.3.4-1 respectively. Construction of the dam proceeded using a downstream method of construction.

A diversion dyke has been constructed around the tailings impoundment area to divert surface runoff to discharge directly to the nearby lake or to local water bodies draining into the lake.

II.3.4.2 Embankment

Prior to construction, muskeg and topsoil was stripped to provide a foundation of undisturbed till. A cutoff was constructed with excavation to bedrock. The starter dam, cutoff and upstream portion of the structure was constructed with compacted silty till. The downstream portion of the embankment was constructed using compacted sandy till. Typical properties of the embankment materials are shown on Table II.3.4-1. Typical ranges for grain size curves for the embankment materials are shown on Figures II.3.4-2 and -3. Compaction specifications for the fill materials are shown on Figures II.3.4-4 and -5. The embankment materials were compacted at a water content not exceeding 8 percent, with compaction to be not less than 95 percent of the maximum dry density determined by the Modified Proctor method. An average permeability for the embankment materials was determined to be 1×10^{-6} m/s.

II.3.4.3 Liner

Only the natural geologic barriers (peat, till and bedrock) were incorporated into the design at the W.T. site.

II.3.4.4 Underdrains

Seepage control through the containment dam is provided by the use of a filter blanket and collection trench at the downstream toe of the dam. The 1000 mm thick filter blanket has been constructed of locally available sand and gravel. The grain size distribution for the free draining filter material is shown on Figure II.3.4-6. The filter blanket was compacted in 200 mm lifts with no control specified. Seepage is collected in a trench constructed at the downstream toe and backfilled with coarse grained gravel. Seepage collected is drained to the treatment pond.

II.3.4.5 Cover

Decommissioning consisted of grading the tailings to have a 2% cross slope after consolidation had occurred. Several covers were then considered.

TABLE II.3.3-4

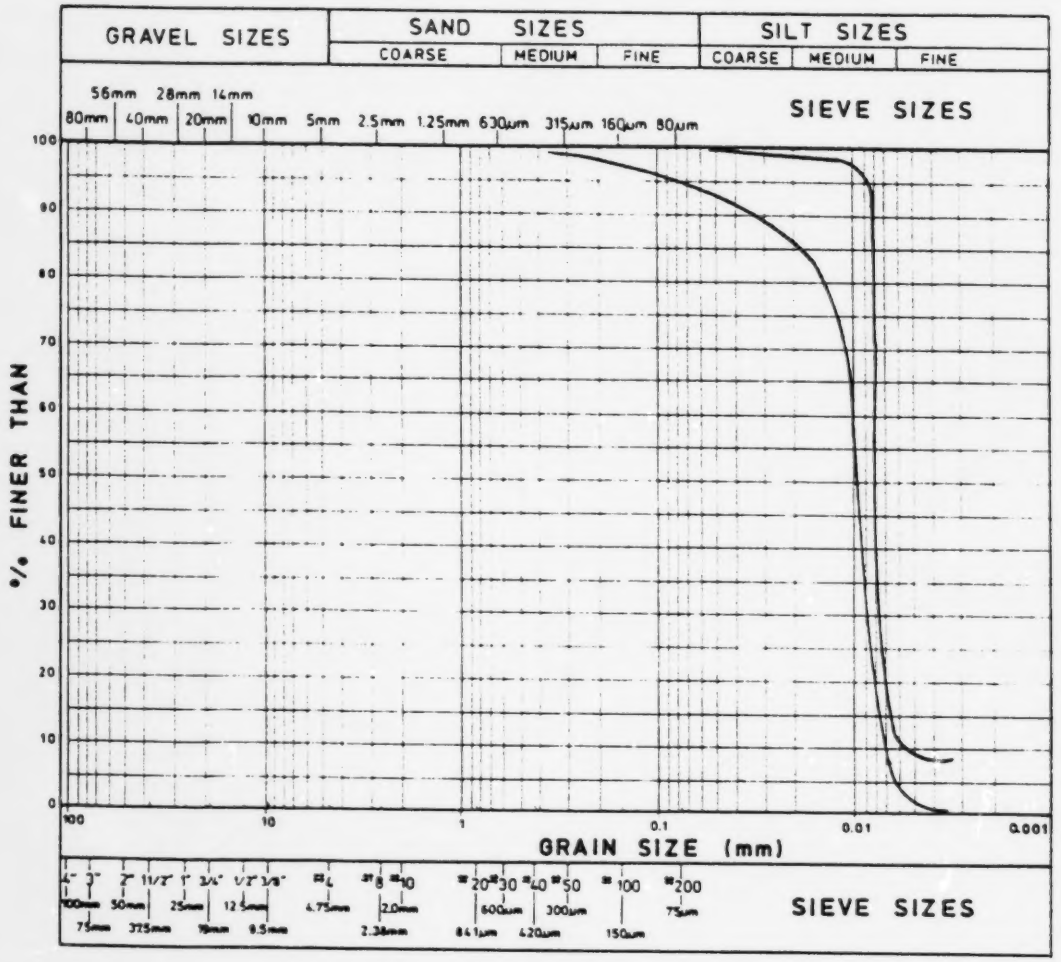
PHYSICAL PROPERTIES OF W.T. MILL TAILINGS

	FINE GRAINED	COARSE GRAINED
WATER CONTENT (%)	100.7	88.0
SPECIFIC GRAVITY	2.8	2.8
VOID RATIO	2.8	3.4
DRY DENSITY (Mg/m^3)	0.65	0.85
W.T. SAND (%)	0-5	18-45
W.T. SILT AND CLAY (%)	95-100	55-82
PERMEABILITY (m/s)	5×10^{-6}	8×10^{-6}
COMPRESSION INDEX	1.2	0.65
COEF. OF COMPRESSIBILITY (m^2/y)	33.9	50.9
EFFECTIVE COHESION (kPa)	13.8	0
FRICTION ANGLE (degrees)	35	37

TABLE II.3.4-1

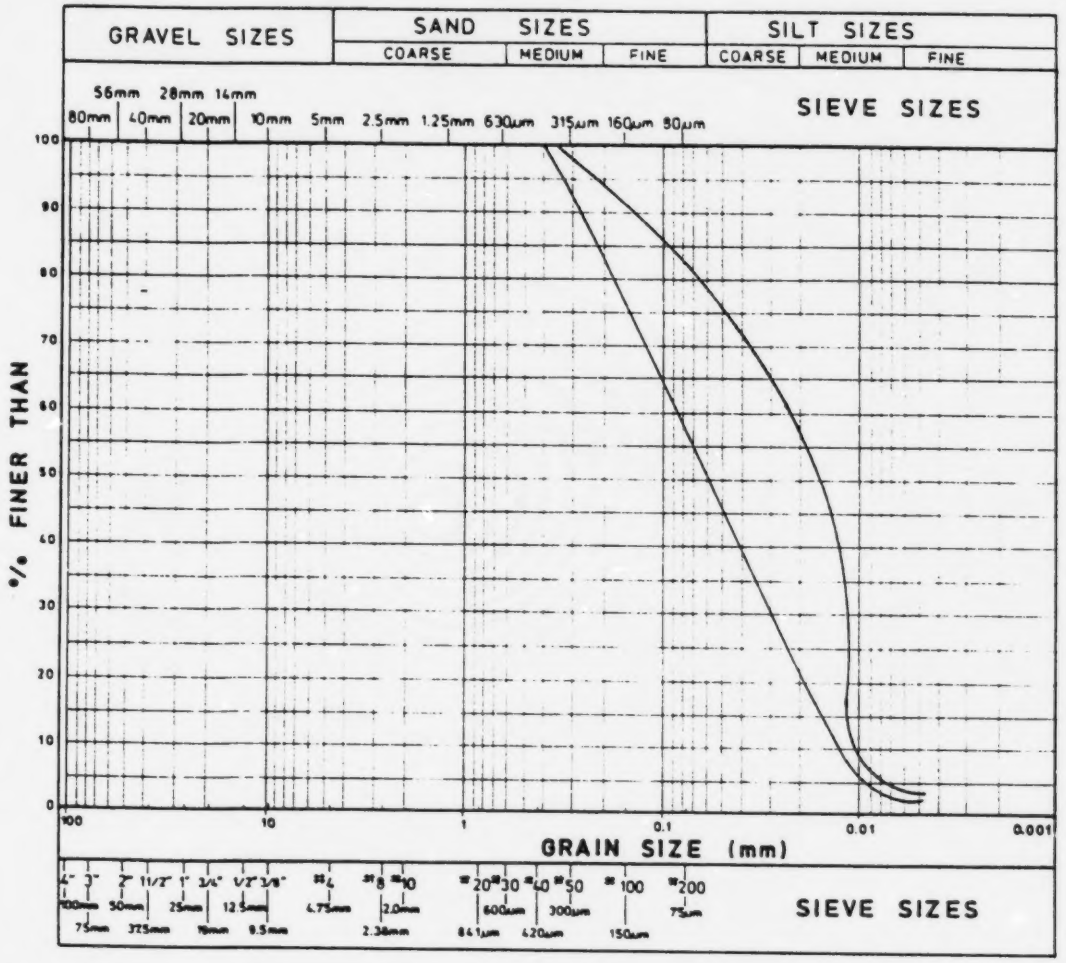
PROPERTIES OF W.T. EMBANKMENT MATERIALS

PHYSICAL PROPERTIES		SILTY TILL	SANDY TILL
GRADATION (% BY WEIGHT)	Gravel	5-30	0-60
	Sand	20-75	15-60
	Silt and Clay	20-50	10-45
COMPACTION CHARACTERISTICS (Modified Proctor)	Water Content (%)	6.2	6.6
	Dry Unit Weight (Mg/m^3)	2.16	2.08
EFFECTIVE SHEAR STRENGTH			
Angle of internal friction (degrees)		35	35
Cohesion (kPa)		0	0
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		1×10^{-6}	-



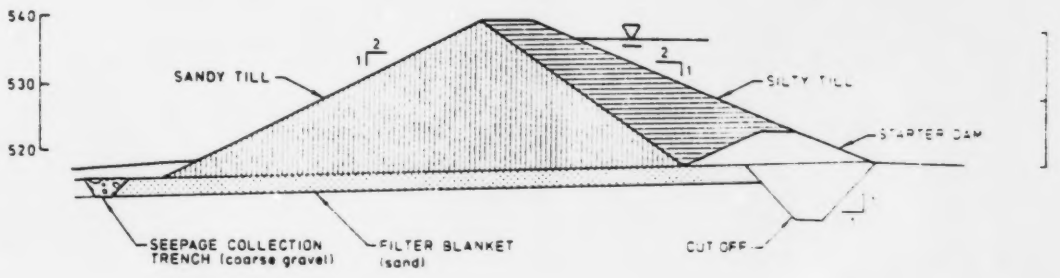
GRAIN SIZE CURVES FOR FINE GRAINED TAILINGS
(SASKATCHEWAN GENERIC WET TAILINGS SITE)

FIGURE 11.3.3-1



GRAIN SIZE CURVES FOR COARSE GRAINED TAILINGS
(SASKATCHEWAN GENERIC WET TAILINGS SITE)

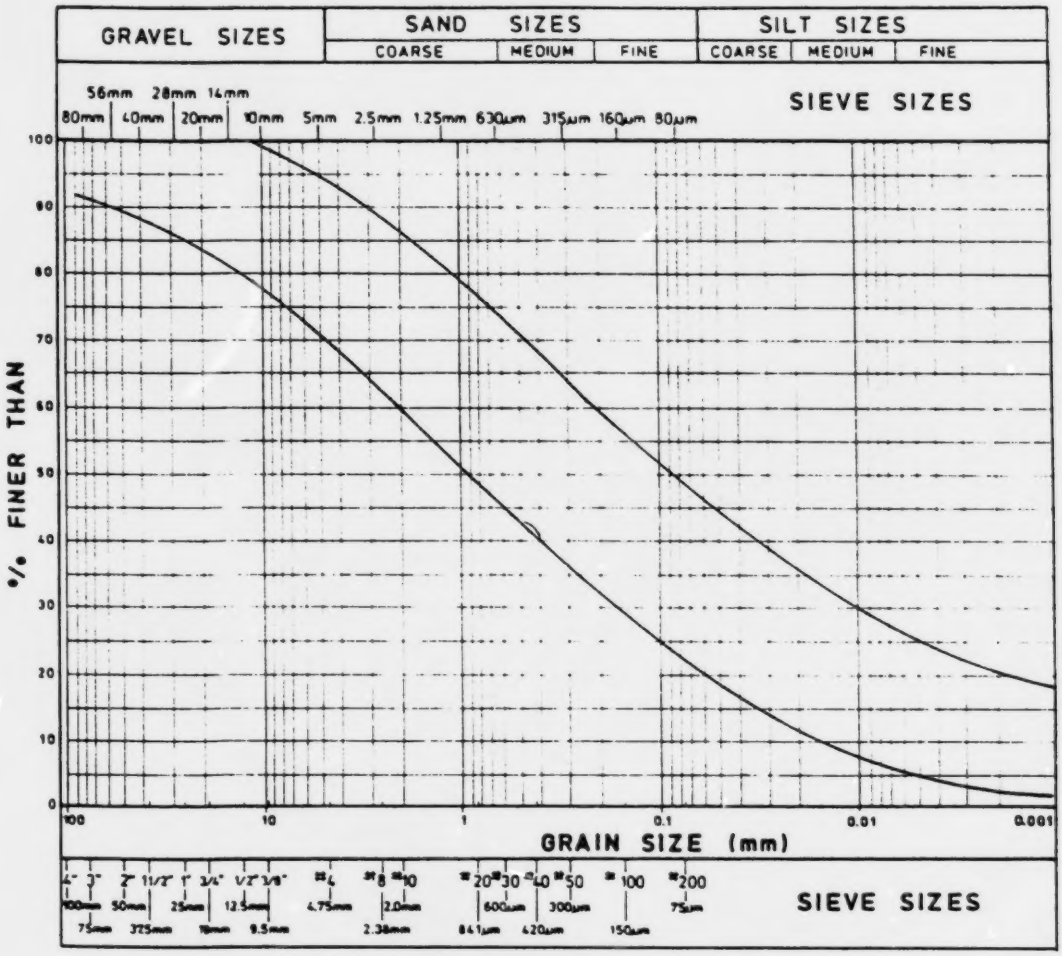
FIGURE II.3.3-2



W.T. TAILINGS DAM CROSS SECTION

(SASKATCHEWAN GENERIC WET TAILINGS SITE)

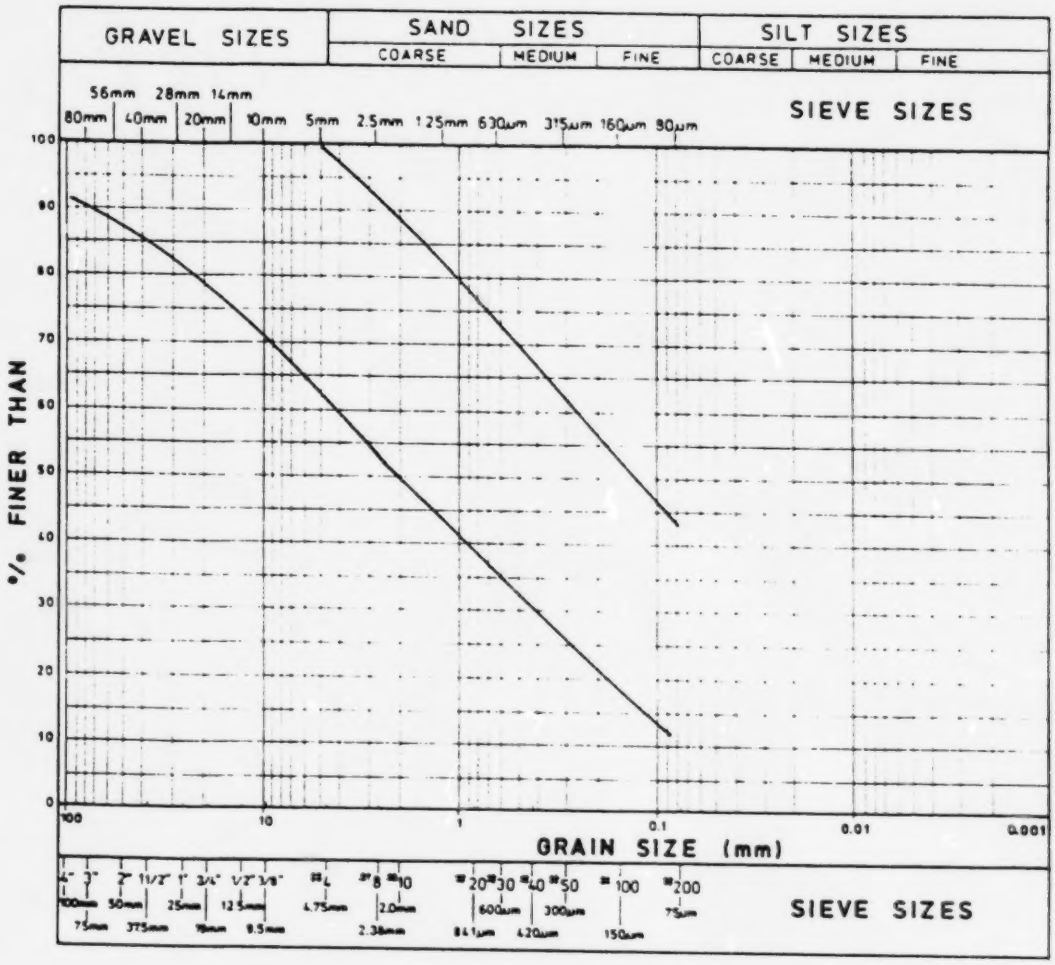
FIGURE II.3.4-1



TYPICAL GRAIN SIZE RANGE, SILTY TILL

(SASKATCHEWAN GENERIC WET TAILINGS SITE)

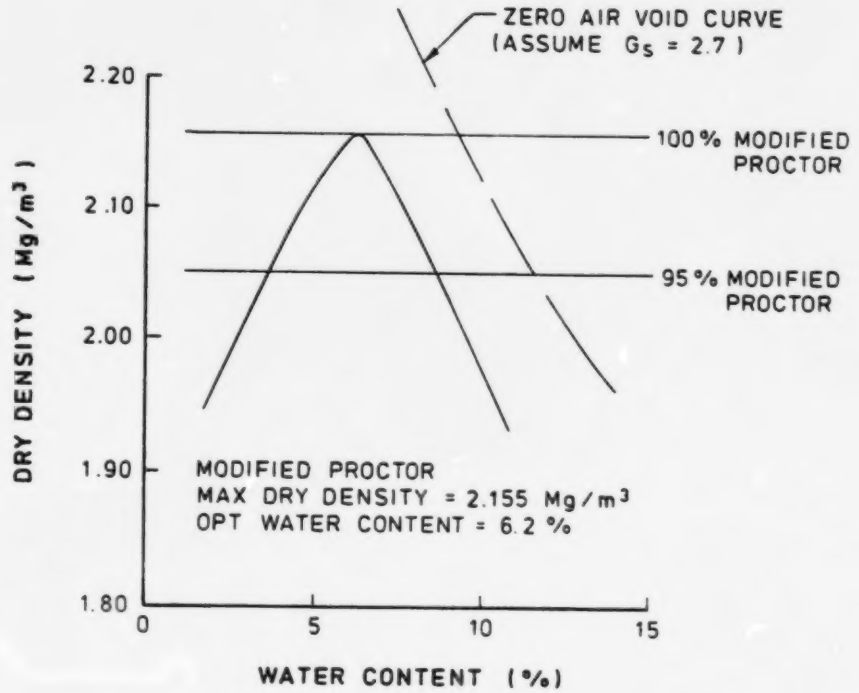
FIGURE 11.3.4-2



TYPICAL GRAIN SIZE RANGE, SANDY TILL

(SASKATCHEWAN GENERIC WET TAILINGS SITE)

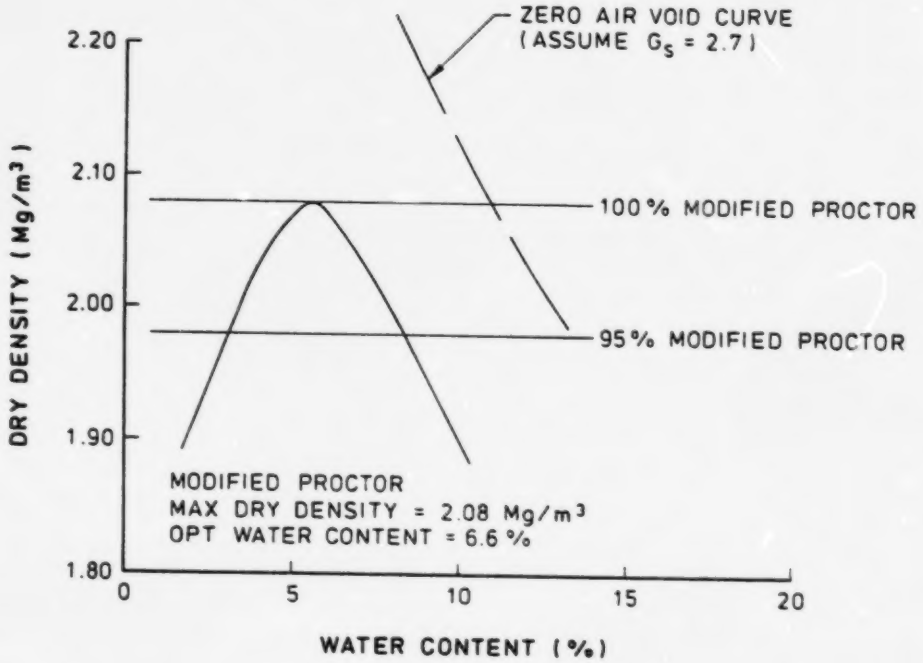
FIGURE 11.3.4-3



COMPACTION SPECIFICATIONS, SILTY TILL

(SASKATCHEWAN GENERIC WET TAILINGS SITE)

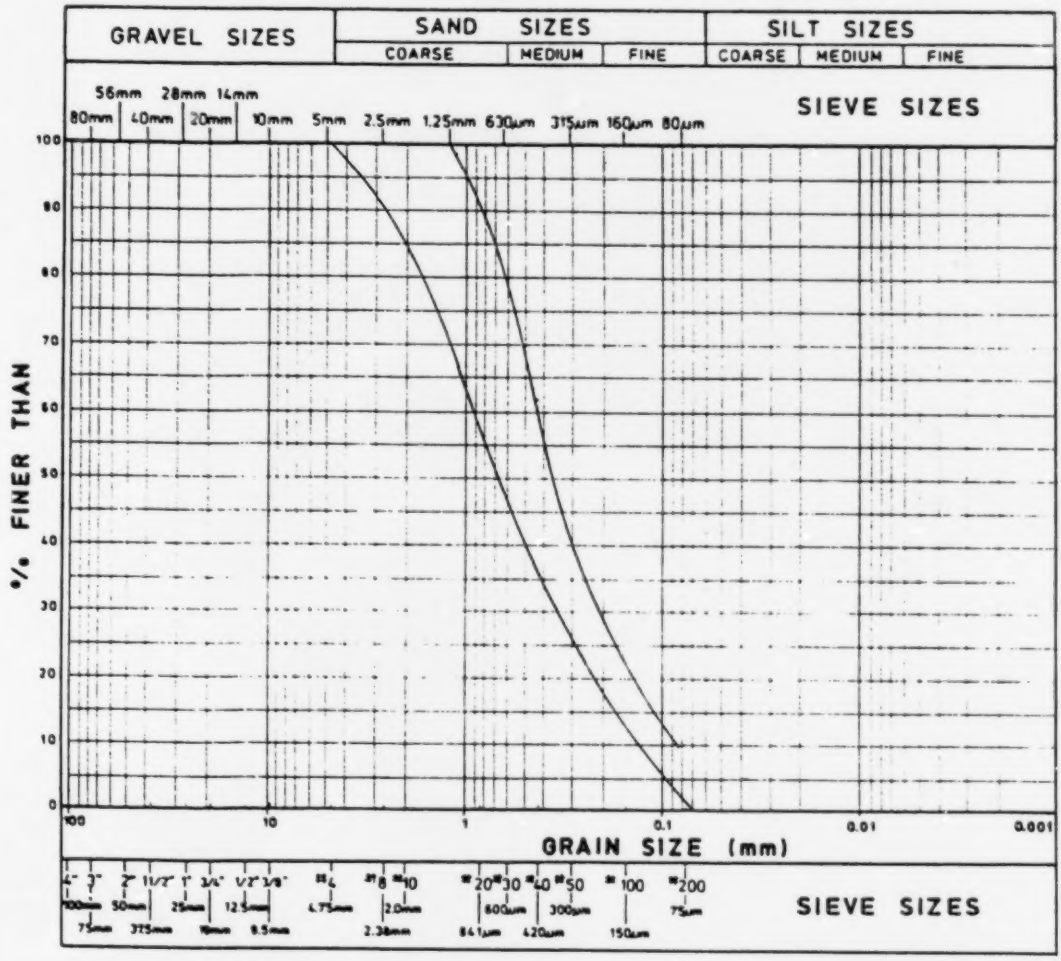
FIGURE II.3.4-4



COMPACTION SPECIFICATIONS, SANDY TILL

(SASKATCHEWAN GENERIC WET TAILINGS SITE)

FIGURE II.3.4-5



TYPICAL GRAIN SIZE RANGE, UNDERDRAIN MATERIAL

(SASKATCHEWAN GENERIC WET TAILINGS SITE)

FIGURE II.3.4-6

These included:

- direct vegetation
- a thin (600 mm) cover of soil, waste rock and direct vegetation
- a thick cover consisting of common fill and bedrock waste to the desired thickness
- a thick (3000 mm) zoned cover as described in Table II.3.4-2

Typical decommissioning layouts and cross sections are shown in Figures II.3.4-7 and -8.

The cover was graded to accommodate consolidation of the tailings (discussed in subsequent sections) and to provide drainage to the perimeter of the impoundment area. Surface runoff has been diverted directly to the nearby muskeg which drains to the lake. Where erosion protection was necessary, a filter blanket of sand and gravel was placed under crushed rock rip rap.

The depth of frost penetration through the cover material and in tailings was estimated. Based on the freezing index for the area, a depth of frost penetration for a cover consisting of silty till with a dry density of 1.9 Mg/m^3 at an average water content of 8 percent results in frost penetration of approximately 3 m. No effort was made during the operation of the tailings area to ensure that complete thawing of tailings frozen during winter deposition occurred. Thus, areas of permanently frozen tailings exist.

II.3.4.6 Diversions

A diversion dyke has been constructed to channel surface runoff around the tailings impoundment. Surface runoff is routed to the lake via a boggy area southwest of the tailings impoundment.

II.3.4.7 Seepage Control

Seepage was collected from the underdrainage system as the tailings consolidated. However, once the precipitation ponds were decommissioned, no further seepage control existed and seepage discharged freely to the muskeg area.

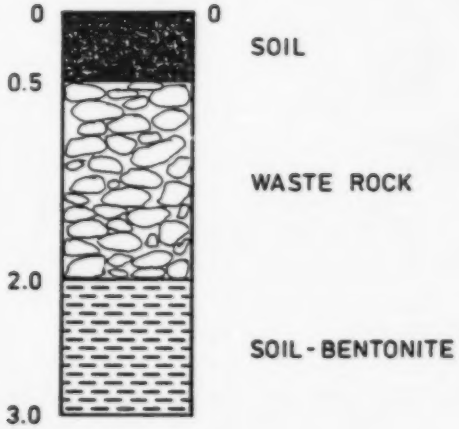
II.3.5 TAILINGS DEPOSIT CHARACTERIZATION

Tailings have been discharged from locations along the southwestern containment dam and the north end of the impoundment facility. The discharge points were moved periodically in an effort to maintain an even distribution of tailings within the basin and a centrally located decant pond. This system of operation resulted in the coarser grained fraction of the tailings being deposited primarily along the north and south ends of the impoundment and the finer grained fraction (slimes) primarily in the central region in the vicinity of the decant pond. Typical grain size distributions for the tailings and physical properties have previously been described.

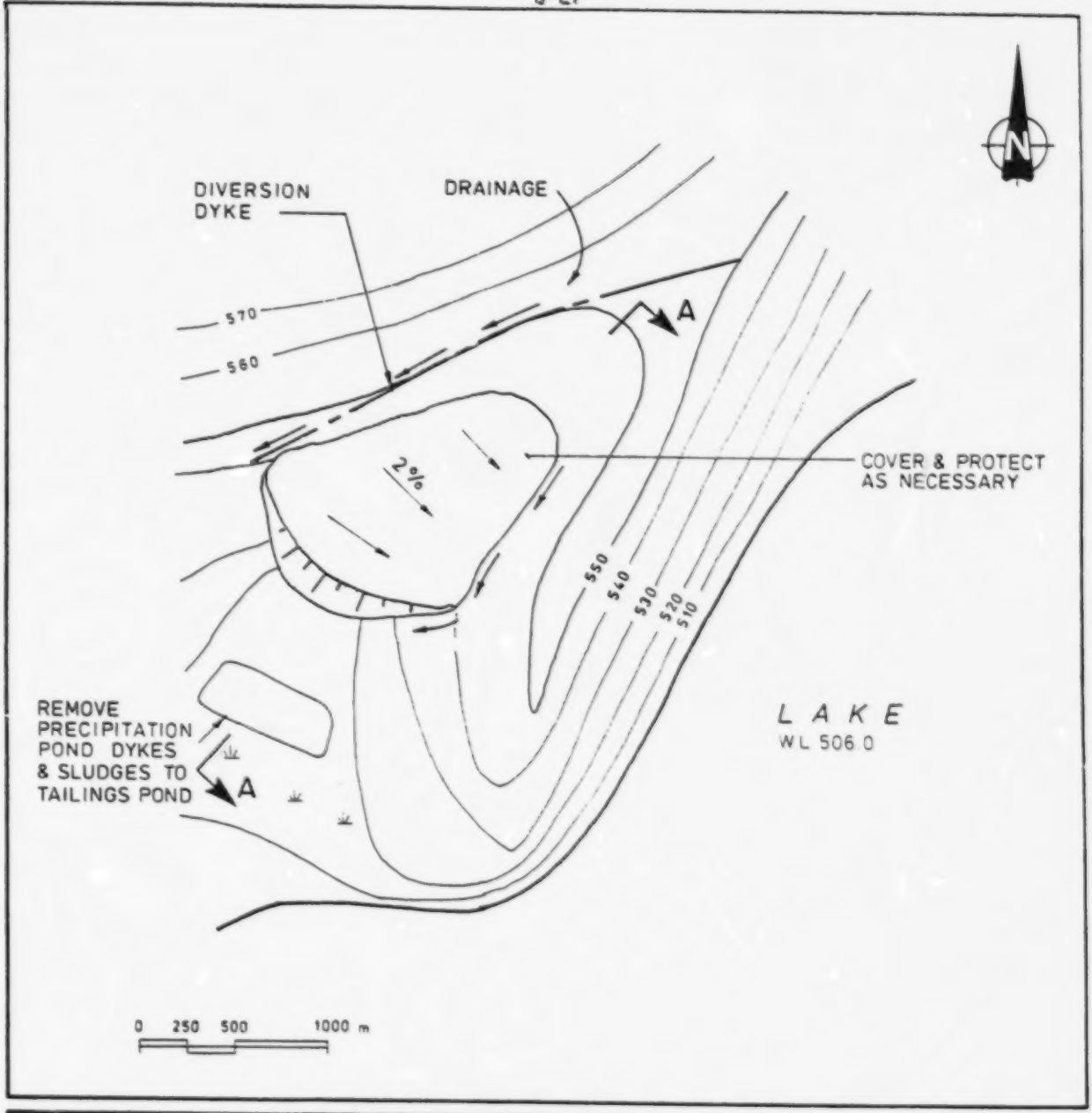
TABLE II.3.4-2

CHARACTERISTICS OF THICK ZONED COVER, W.T. SITE

ZONE	THICKNESS (mm)	PURPOSE	MATERIAL PROPERTIES
Soil	500	rooting medium	random till borrow
Waste Rock	1500	drainage layer, capillarity break, biobarrier	waste rock, 100% -300 mm, 5% -75 um
Soil-bentonite	1000	radon barrier	4% bentonite, $k=10^{-9}$ m/s



COVER PROFILE

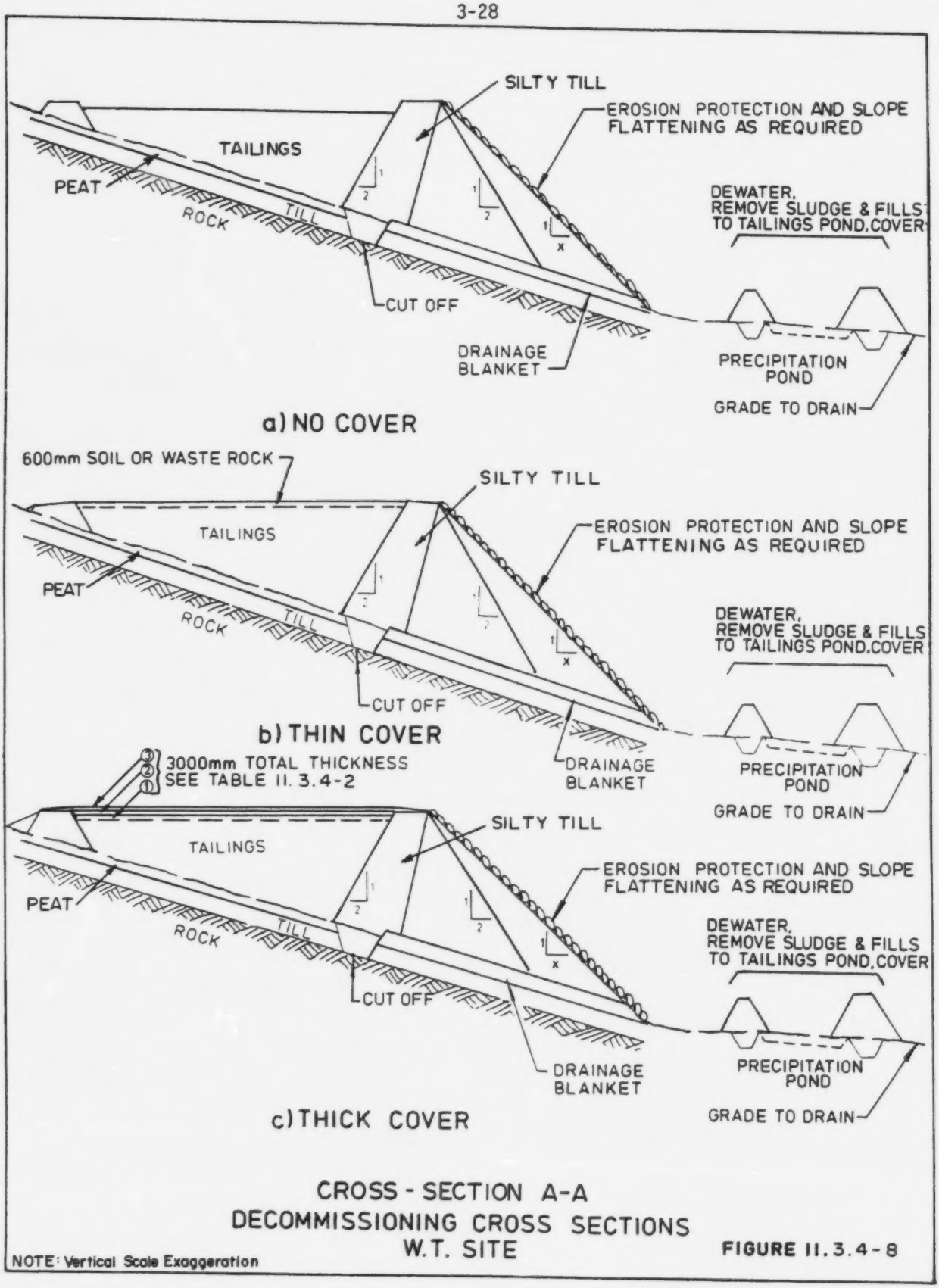


SITE PLAN

W.T. (WET TAILINGS) DECOMMISSIONING SCHEME

(SASKATCHEWAN GENERIC WET TAILINGS SITE)

FIGURE II.3.4-7



CROSS - SECTION A-A
DECOMMISSIONING CROSS SECTIONS
W.T. SITE

NOTE: Vertical Scale Exaggeration

FIGURE 11.3.4-8

Limited areas of the impoundment surface, over the coarse tailings areas, are trafficable in the summer. The majority of the impoundment has a surface of soft saturated tailings and tailings slimes. Some of this area can be made trafficable by installing drainage, however the greater part is slow draining and soft. Winter access is possible on the frozen tailings to all parts of the impoundment.

The rate and location of deposition were not controlled during the winter months, resulting in areas within the impoundment where accumulations of tailings up to 3 m or more were common. It is within these areas that permanently frozen tailings are encountered.

At the time of decommissioning, approximately 20 m of tailings were contained in the impoundment area. Based on the consolidation testing conducted on tailings samples, the estimated consolidation for the fine and coarse grained tailings with 600 mm and 3000 mm of cover, shown on Table II.3.5-1, indicates consolidation of up to 2.6 m. The estimated time for 50% and 95% consolidation considering single drainage is 2.4 years and 13.3 years respectively.

TABLE II.3.5-1

ESTIMATED CONSOLIDATION FOR TAILINGS AND COVER,
W.T. SITE

	THICKNESS OF COVER	
	600 mm	3000 mm
COARSE GRAINED TAILINGS	1.32 m	1.73 m
FINE GRAINED TAILINGS	2.33 m	2.59 m

II.4.0 TYPICAL SASKATCHEWAN SEMIDRY TAILINGS SITE

II.4.1 IMPOUNDMENT LAYOUT

The semidry tailings (S.D.) site is situated against a drumlinoid till landform adjacent to a lake. The tailings site is shown on Figure II.4.1-1. It has an impoundment area of 90 ha and the maximum depth of tailings is 20 m. The mill site was located approximately 300 m northeast of the tailings impoundment area. Tailings from the mill were pumped by pipeline to the impoundment area. Supernatant and seepage were collected through an underdrain system and returned to treatment ponds located near the mill.

The tailings disposal site is underlain with drift varying in thickness from 7 to 66 m. It consists of a thin veneer of silt overlying till which has a matrix of fine to medium grained sand. On the low lying areas, peat is the surficial material.

The terrain northwest of the tailings impoundment area is a gently sloping plain. All of the confinement dykes are founded on till. The impoundment area has been excavated with silty, sandy till borrow being used for the construction of the dykes.

The design of the impoundment area incorporates an underdrainage system which collects the supernatant and seepage. The liquids are channelled to a sump area from where it drains to treatment ponds. The bottom of the impoundment area was shaped to provide drainage to the southeast. The till surface was then scarified, mixed with bentonite, moisture conditioned and recompacted to form an underseal upon which a free draining filter sand was placed. A typical section is shown on Figure II.4.1-2.

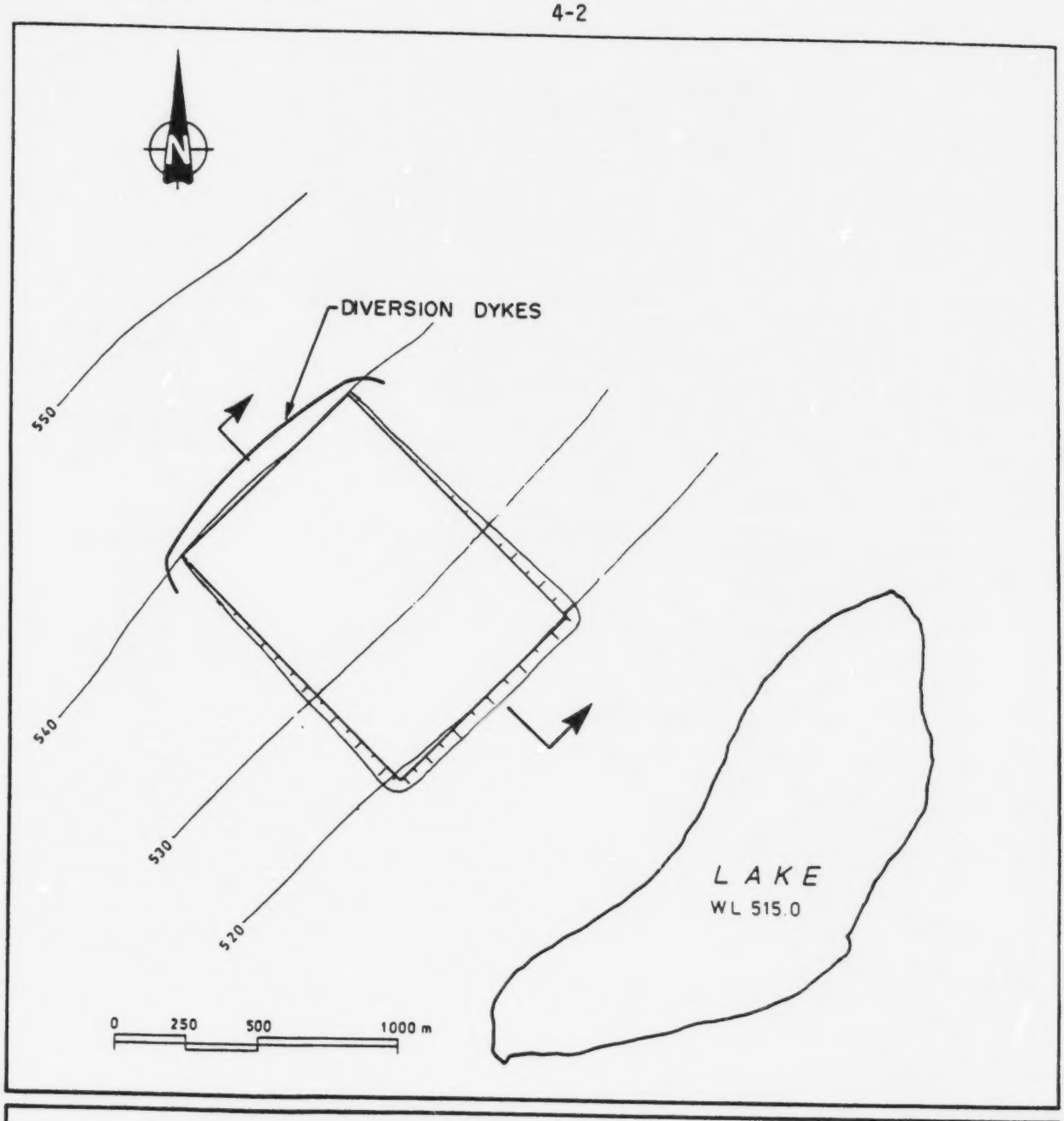
The underseal and filter blanket extends to the downstream toe of the confinement dyke to the collection system. The dykes are of zone construction with a soil bentonite core bounded on the upstream side by compacted sand till and on the downstream side by compacted till.

II.4.2 ENVIRONMENTAL SETTING

II.4.2.1 Meteorological Data

The climate in this study area is similar to that at the WT site and is characterized by a short cool summer boreal forest climate. A summary of precipitation records can be found in section II.3.2.1. Mean monthly temperatures are shown on Figure II.4.2-1. The mean annual temperature is -2.7 degrees C, with mean daily temperatures ranging from -25 degrees C in January to 16 degrees C in July. Extreme temperatures range from -50 degrees C to 35 degrees C. The average freezing index for the area is 2780 degrees C-days.

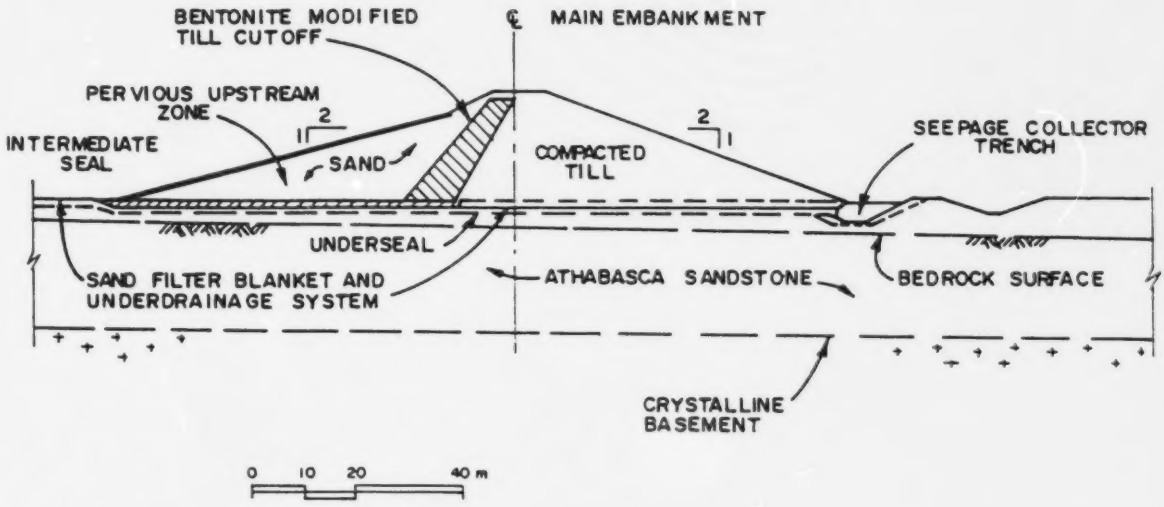
In order to develop a realistic representative set of meteorological, groundwater, geology and surface water quality data, use was made of actual data from the Key Lake site.



SITE PLAN

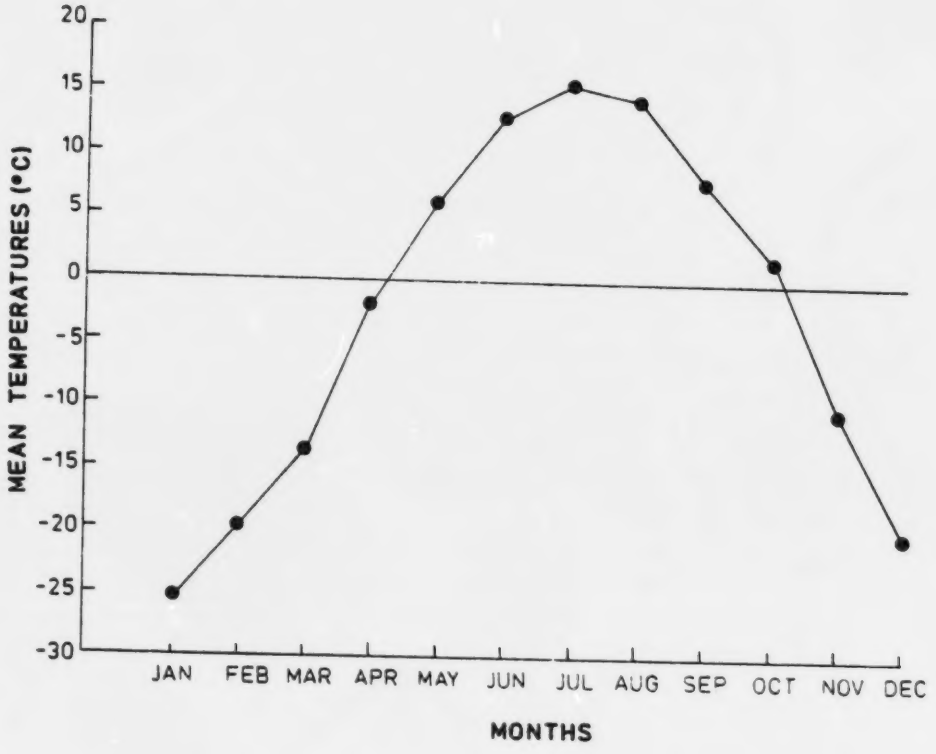
S.D.(SEMIDRY) TAILINGS SITE LAYOUT
(SASKATCHEWAN GENERIC SITE)

FIGURE 11.4.1-1



S.D. SITE, MAIN EMBANKMENT CROSS-SECTION
(SASKATCHEWAN GENERIC SEMI-DRY SITE)

FIGURE II.4.1-2



MONTHLY TEMPERATURE, S.D. SITE

(SASKATCHEWAN GENERIC SEMI-DRY SITE)

FIGURE II. 4.2-1

II.4.2.2 Topography and Geomorphology

The origin, nature and structure of the basement rocks has been discussed previously in section II.3.2.2. The uranium mine is located within the Canadian Shield, a glacially scoured complex of geologically ancient rocks. The surface of the Precambrian rock has been extensively scoured by glacial erosion and covered with glacial and proglacial sediments. The predominant landform in the S.D. tailings study area is ground moraine. The till surface is drumlinoid in nature, with some drumlins in the area over 50 m in height. Other landforms present in the area are eskers and kames. These landforms are good sources of granular construction materials.

Topographic depressions are infilled with peat. The entire area is within the zone of discontinuous permafrost and the peat filled depressions often contain ice-rich, permanently frozen soil.

The regional drainage is generally poorly integrated and is comprised of many landlocked lakes and bogs. The surface water is generally of very high quality with a very low mineral content, most often with a total dissolved solid content of less than 200 mg/L. The pH of the water varies from about 5.5 to 8.0, but may be as low as 3.0 in stagnant muskeg areas.

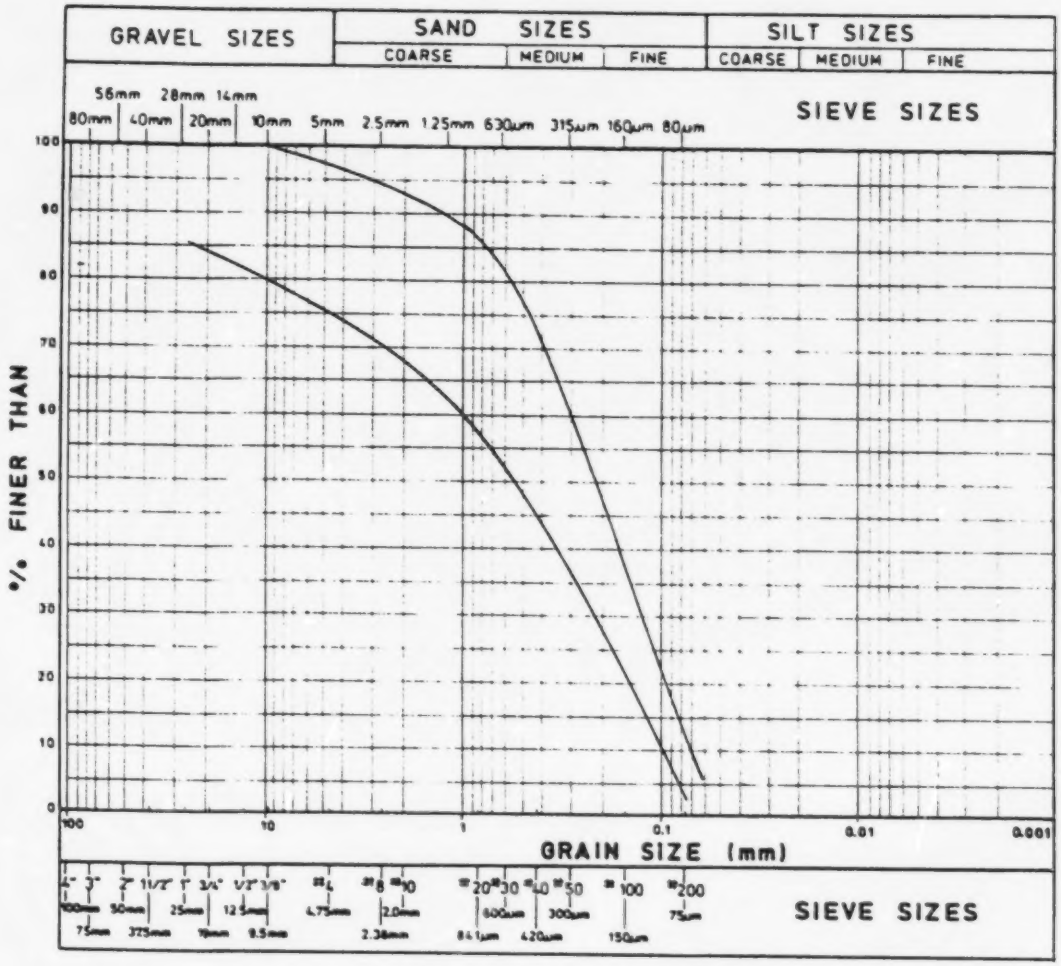
Elevated water bodies and peat bogs provide ample recharge for the groundwater systems. Major aquifers include glacial outwash plains comprised primarily of sand, glacial till strata, and fractured bedrock. The drift and fractured bedrock is relatively permeable but the hydraulic conductivity of the bedrock generally decreases with depth. Groundwater quality is generally very good and closely reflects the surface water quality.

II.4.2.3 Site Geology

Stratigraphy in the impoundment area consists of a medium dense to very dense, sandy till. Some concentrations of boulders and strata with an increased proportion of silt and clay occur near the surface. In general, the till is composed of 19 percent gravel sizes by weight, 76 percent sand sizes and 5 percent silt and clay sizes. A typical grain size distribution for the till encountered is shown on Figure II.4.2-2. A thin covering of peat is evident in low lying areas. Till in the area varies in thickness, ranging from a minimum of 7 m to a maximum of 66 m. A mean value for the permeability is reported to be 3×10^{-6} m/s.

The Athabasca Formation underlies the overburden material over the area of the impoundment. It varies in thickness to a maximum of 25 m and consists of coarse grained sandstones with a basal quartz pebble conglomerate. The reported mean permeability for the Athabasca Formation is 3×10^{-6} m/s.

Crystalline basement rocks consisting mainly of granite gneisses, some biotite rich gneisses and frequent pegmatitic fractions underlies the Athabasca Formation. It has a reported mean permeability of 5.5×10^{-7} m/s.



GRAIN SIZE DISTRIBUTION FOR TILL

(SASKATCHEWAN GENERIC SEMI-DRY SITE)

FIGURE II.4.2-2

II.4.2.4 Groundwater

A single groundwater system exists within the surficial till and the Athabasca Formation. The groundwater system in the area is shallow, with the water level generally within 5 m of the ground surface. In the vicinity of the tailings impoundment, groundwater flow is southeast towards the lake.

II.4.2.5 Hydrology

The contributing watershed draining towards the tailings pond has a gross area of 80 ha with an average slope of 2%. The longest drainage path is 1000 m. The watershed is sparsely forested till with a thin mat of organic material overlying the till.

II.4.2.6 Groundwater and Surface Water Quality

Groundwater was sampled and analyzed for radionuclides, trace metals and major ions. Table II.4.2-1 shows the mean values for the parameters measured. In general, the groundwater has a mean pH of 6.5.

Baseline surface water quality is shown on Table II.4.2-2.

II.4.3 TAILINGS CHARACTERIZATION

The ore body mined at the S.D. site consists of euhedral and radially textured pitchblende, sooty pitchblende and small amounts of coffinite. Mineralization of uranium is associated with nickel arsenides. Typical analyses for the ore is shown on Table II.4.3-1. In order to develop realistic chemical data, much of the ore, tailings and tailings liquid quality data was taken directly from representative Key Lake data.

The S.D. mill utilized semi-autogenous grinding and acid leaching. Uranium is precipitated with ammonia. Leach tailings were neutralized with lime. The neutralized tailings were then thickened before being discharged to the tailings impoundment. Liquid effluents collected at the tailings site were pumped back to treatment ponds, where they were treated with barium chloride and lime before being clarified and adjusted for pH prior to discharge to the environment.

Typical chemical properties of the mill effluent, tailings effluent and tailings seepage are shown on Table II.4.3-2. Pore water chemistry is shown on Table II.4.3-3.

A field investigation of the insitu tailings was conducted to evaluate the geotechnical properties of the tails. Physical properties of the tailings are summarized on Table II.4.3-4. A typical grain size curve for the tailings is shown on Figure II.4.3-1.

TABLE II.4.2-1

BASELINE GROUNDWATER QUALITY, S.D. SITE

	(mg/L)
pH	6.5
Cond	18 umho/cm^2
O-PO_4	0.08
TKN	
NH_3	0.02
NO_3	0.10
SO_4	<1.0
Cl	0.22
Ca	<0.1
Na	0.3
Mg	0.17
K	<0.1
T. Ra^{226}	<0.10 pCi/L
U	0.011
Po^{210}	8.6 pCi/L
Th^{232}	0.116 pCi/L
As	0.0097
Ba	0.10
Cd	0.001
Cr	0.009
Cu	0.012
F	<0.01
Fe	2.29
Hg	<0.00005
Mn	0.074
Ni	0.019
Pb	0.010
Se	<0.002
V	<0.01
Zn	0.16

Note: pH expressed in standard units; all other parameters in mg/L except where noted

TABLE II.4.2-2

BASELINE SURFACE WATER QUALITY, S.D. SITE

	(mg/L)
pH	6.90
O-PO_4	0.06
T.PO_4	0.07
NH_3	0.02
NO_3	0.005
TDS	54.0
TSS	4.0
SO_4	<1.0
CL	<1.0
HCO_3	8.1
CO_3	0.0
Ca	0.71
Na	1.25
Mg	0.21
K	0.71
D. Ra^{226}	<0.1 pCi/L
T. Ra^{226}	<0.1 pCi/L
U	<0.0005 pCi/L
Pb^{210}	0.10 pCi/L
Po^{210}	<0.1 pCi/L
Th^{230}	<0.7 pCi/L
As	<0.0005
Ba	0.005
Cd	<0.0005
Cr	0.017
Cu	<0.001
F	0.076
Fe	0.042
Hg	<0.00005
Mn	0.002
Ni	<0.001
Pb	0.003
Se	<0.002
V	<0.01
Zn	0.005

Note: pH expressed in standard units; all other parameters in mg/L except where noted.

TABLE II.4.3-1

TYPICAL ANALYSIS OF S.D. MINE ORE

Element	%
$Ra-^{226}$	300 Bq/g
U_3O_8	2.9
SiO_2	50
Fe	3
S	0.8
Cu	0.09
Zn	0.03
Mo	0.03
V	0.09
Ni	1.1
Co	0.08
Ti	0.6
Al	10.3
As	1.1
Ca	0.4
Mg	2.9
Na	0.9
K	1.5
F	n/a
P_2O_5	0.15
CO_2	0.8
Cl	n/a

TABLE II.4.3-2

TYPICAL CHEMICAL PROPERTIES OF TAILINGS LIQUIDS, S.D. MILL

	INCOMING TAILINGS	TAILINGS DECANT	SEEPAGE
pH	6.4-12.1	11.3-11.5	7.1-7.4
Cond	3130-6810*	3180*	2030*
NH_3	11-33		34
NO_3	0.01-0.06		0.03
SO_4	1310-3450	1590-1720	1150-1470
Cl	14-387		16
Ca	520-1050	655-780	374-550
Na	15-210	23-92	24-47
Mg	0.1-510	<0.16	0.63-3.9
K	4.9-30.0	7.8-17	7.8-8.9
D. Ra^{226}	25-420 Bq/L	210 Bq/L	10-45 Bq/L
U	0.004-0.1	3.2-13	0.04-0.13
Pb^{210}	0.4-45 Bq/L	3.0 Bq/L	0.07-0.45 Bq/L
Po^{210}	0.5 Bq/L	2.0 Bq/L	0.2-1.4 Bq/L
Th^{230}	0.5-4.5 Bq/L		
Ag	<0.001	<0.002	<0.001
Al	0-0.15	0.22-0.47	0-6.1
As	0.8-4.6		0.062-0.076
B	0.02-0.52	0.09-0.27	0.02-0.04
Ba	0.01-0.12	0.049-0.052	0.04-0.061
Be	<0.001	<0.001	<0.001
Cd	0-0.004	0.001-0.009	0-0.01
Co	<0.001	<0.001	0-0.009
Cr	0.008-0.024	0.011-0.022	0.004-0.014
Cu	0.005-0.009	0.006-0.008	0.007-0.009
Fe	0.032-0.064	0.046-0.049	0.042-3.8
Mn	0-1.9	<0.001	0.057-4.2
Mo	0.-3.7	0.58-1.3	0.48-0.85
Ni	0.01-0.29	0.005-0.011	0.0411-0.094
P	0.050-0.38	0.07-0.2	0.05-0.08
Pb	0-0.28	<0.005-0.02	0-0.02
Sb	0-0.002		0.002
Se	0.001-0.02		<0.001
Si	0.2-0.8		1.3
Ti	<0.001	<0.001	<0.001
V	0.06-0.21	0.06-0.14	0-0.07
W	0-1.1	0.45-0.89	0.06-0.31
Zn	0.002-0.47	0.001	0.06-0.21
Zr	<0.001		<0.001

Note: pH expressed in standard units; all other parameters in mg/L except where noted

*umho/cm^2

TABLE II.4.3-3

PORE WATER CHEMISTRY OF S.D. TAILINGS

	(mg/L)
pH	9.3-11.1
Ca	582-627
D. Ra^{226}	9.5-55 Bq/L
U	0.0014-0.005
Pb^{210}	0.13-0.7 Bq/L
Po^{210}	-
Th^{230}	0.08-1.6 Bq/L
As	0.26-2.2
Cr	<0.005
Mo	0.43-1.2
Ni	0.016-0.087
Pb	<0.02-0.04
Si	1.8-4.1
W	0.23-0.25
Zn	0.02-0.032

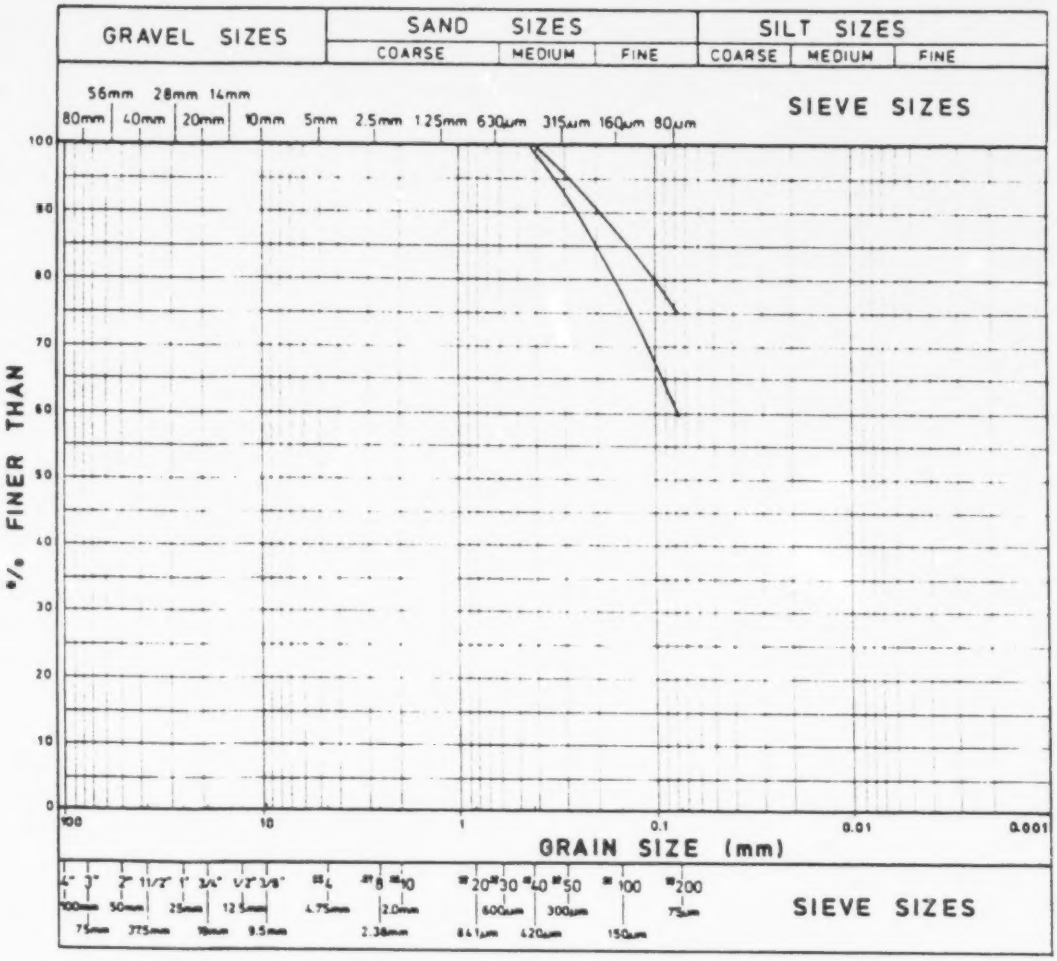
Note: pH expressed in standard units; all other parameters in mg/L except where noted.

TABLE II.4.3-4

PHYSICAL PROPERTIES OF S.D. TAILINGS

WATER CONTENT (%)	50-250 (avg. 132)*
SPECIFIC GRAVITY	2.64*
VOID RATIO	4.6-5.6
DRY DENSITY (Mg/m^3)	0.4-1.4 (Avg. 0.6)*
SAND (% by weight)	15-25
SILT AND CLAY (% by weight)	75-85
PERMEABILITY (m/s)	
(oedometer test)	$0.1\text{-}2.8 \times 10^{-8}$
(permeameter)	$1.1\text{-}1.4 \times 10^{-7}$
COMPRESSION INDEX	2.00
COEF. OF COMPRESSIBILITY (m^2/y)	15-102

*Knight & Piesold, 1986.



GRAIN SIZE CURVE FOR TAILINGS

(SASKATCHEWAN GENERIC SEMI-DRY SITE)

FIGURE II. 4.3-1

II.4.4 DESCRIPTION OF CONTROL STRUCTURES

II.4.4.1 General

As described previously in Section II.4.1, the containment dykes have been constructed with compacted till and sand. The upstream compacted sand serves to decant supernatant liquid and precipitation from the tailings area. The upstream face is protected against erosion by a layer of coarse filter material. Seepage collects in a filter blanket placed over a compacted bentonite modified soil underseal and is collected at the downstream toe of the main embankment in a sump. The dam cross section has been shown on Figure II.4.1-2.

A diversion dyke has been constructed around the tailings impoundment area to divert surface runoff to discharge directly to the nearby lake.

II.4.4.2 Embankment

Construction of the main embankment consists of compacted free draining sand on the upstream side and compacted till on the downstream side. An impermeable zone of bentonite modified till has been constructed to control seepage through the embankment. Typical properties of the embankment materials are shown on Table II.4.4-1. Typical ranges for grain size curves for the embankment materials are shown on Figures II.4.4-1 and -2. Prior to construction, muskeg and topsoil were stripped to provide a foundation of undisturbed till. The majority of the material used for the construction of the embankment originated from the excavation for the tailings pond. Compaction specifications for the fill materials were determined relative to the maximum density as determined using a vibratory table (ASTM 2049) due to the granular nature of the material. The aim was to provide at least 95 percent of the maximum density. No strict control was placed on the water content when compacted because of the relative insensitivity of the dry density to the compaction water content. However, a maximum water content of 8 percent was used as a rule. The maximum dry density for the compacted till material was 2.00 Mg/m^3 and for the sand, 1.77 Mg/m^3. The embankment materials were placed in 300 mm lifts and compacted with a minimum of 4 passes with a vibratory roller. The compactive effort was controlled by the maximum dry density criteria.

Permeability testing was conducted on the granular upstream material to ensure that it served as an efficient method for decanting liquids. An average permeability of 8×10^{-5} m/s was measured.

To protect the compacted sand zone, a coarse grained filter material was placed. Approximately 72 percent by weight was composed of gravel sizes. Approximately 23 percent of the grain sizes were sand sizes and 5 percent or less was made up of silt and clay sizes.

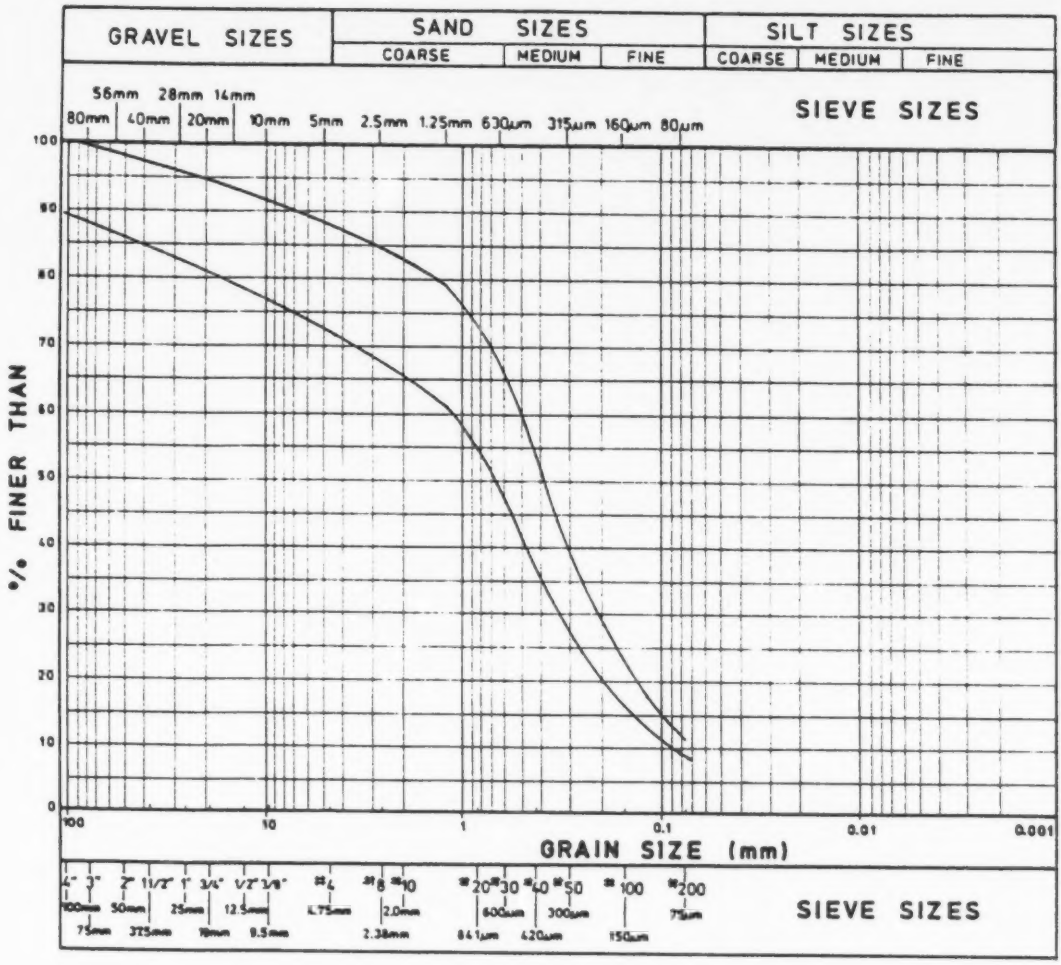
II.4.4.3 Liner

The liner system at the S.D. site consists of a compacted bentonite modified till underseal and embankment barrier. The base of the tailings impoundment was graded at approximately 1 percent down towards the southeast to ensure drainage of seepage and supernatant. Typical physical

TABLE II.4.4-1

PHYSICAL PROPERTIES OF S.D. EMBANKMENT MATERIALS

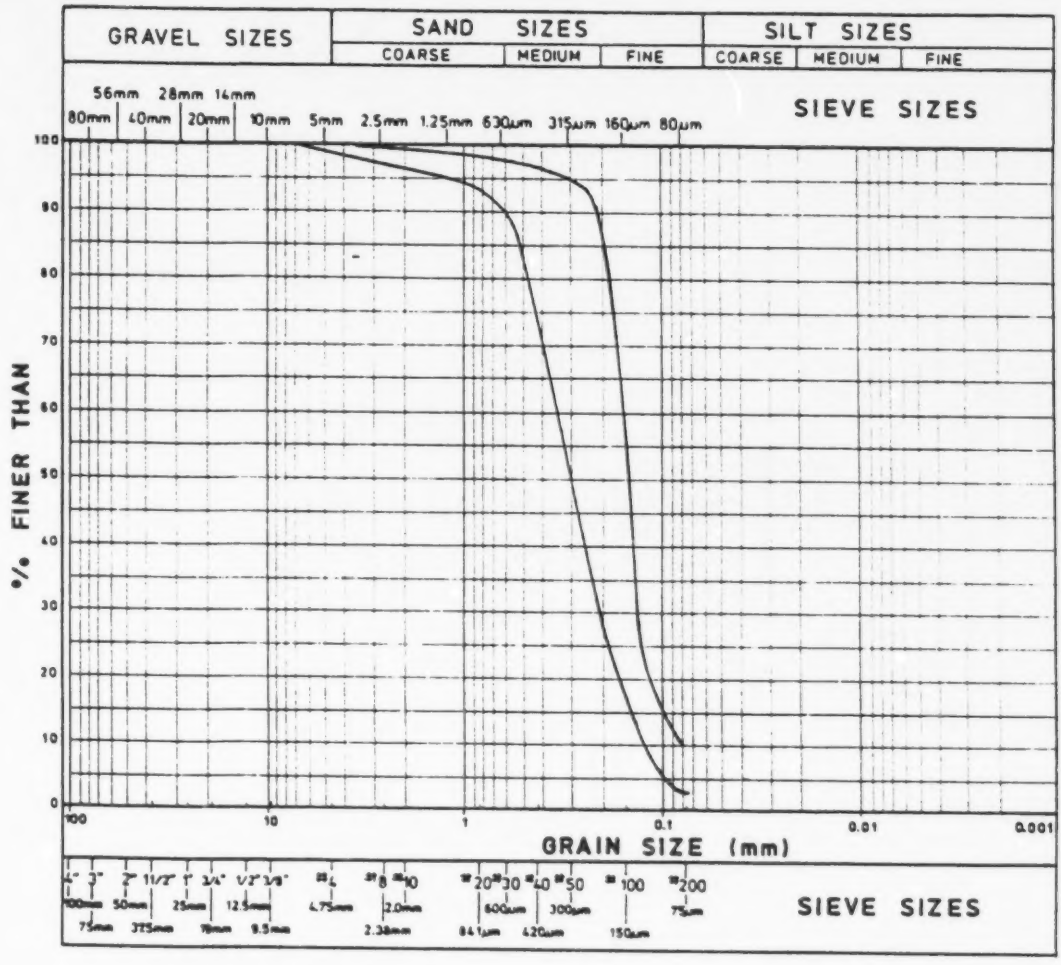
PHYSICAL PROPERTIES		TILL	SAND
GRADATION (% BY WEIGHT)	Gravel	12-28	0-2
	Sand	60-79	88-98
	Silt and Clay	9-12	2-10
SPECIFIC GRAVITY		2.7 (est.)	
COMPACTION CHARACTERISTICS (ASTM 2049)	Max Dry Density (Mg/m^3)	2.00	1.77
EFFECTIVE SHEAR STRENGTH			
Angle of internal friction (degrees)		35	
Cohesion (kPa)		0	
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		1×10^{-6}	8×10^{-5}



GRAIN SIZE RANGE FOR TILL

(SASKATCHEWAN GENERIC SEMI-DRY SITE)

FIGURE II.4.4-1



GRAIN SIZE RANGE FOR FILTER SAND

(SASKATCHEWAN GENERIC SEMI-DRY SITE)

FIGURE 11.4.4-2

properties of the bentonite modified liner are shown on Table II.4.4-2. Construction of the underseal was accomplished by replacing the insitu material with 300 mm of screened till and modifying to a depth of 200 mm. Bentonite was blended into the till at a rate of between 10 and 18 kg/m^2 at a moulding moisture content of 8 to 11 percent by weight. The amount of bentonite added was dependent upon the desired design permeability of 1 X 10^{-8} m/s. The number of passes for the compaction equipment was dependent upon the number required to achieve an objective of 95 percent of Modified Proctor dry density. Figure II.4.4-3 shows a typical dry density versus moisture content relationship for the compacted liner. Figure II.4.4-4 shows the grain size curve for the modified till material used for the liner. The average hydraulic conductivity of the liner material was 1 X 10^{-8} m/s.

II.4.4.4 Underdrains

Sand used for the filter blanket was outwash sand that occurred as overburden and is the same material as that used for the upstream portion of the embankment. The sand was compacted in two lifts of 500 mm to at least 95 percent of the maximum dry density as determined by ASTM 2049. The maximum dry density determined using this method was 1.77 Mg/m^3. No moisture control was specified. The hydraulic conductivity measured was approximately 8 X 10^{-5} m/s.

II.4.4.5 Cover

Decommissioning procedures consisted of contouring the tailings to have a 2% cross slope after the tailings have consolidated. The tailings could then be covered with:

- direct vegetation, or,
- thin (600 mm) till, or,
- thick (3000 mm) of common fill (sand and/or till), or,
- thick (3000 mm) zoned covers for maximum radon attenuation

In all cases the sand filter would be extended and the dyke slopes flattened and rip rap protected against erosion. Slopes flattened to between 3:1 and 6:1 were considered. The dykes would function as diversion works to divert drainage around the deposit. A typical layout and sections for the scheme is shown in Figures II.4.4-5 and -6 respectively. Table II.4.4-3 summarizes the characteristics of the thick zoned cover.

The depth of frost penetration through the cover material and in tailings was estimated. Based on the freezing index for the area, a depth of frost penetration for a cover consisting of silty till compacted with a dry density of 1.9 Mg/m^3 at an average water content of 8 percent results in frost penetration of approximately 2.5 m. Deposition of tailings had ample time to thaw. Thus, no frozen tailings are expected in the impoundment area.

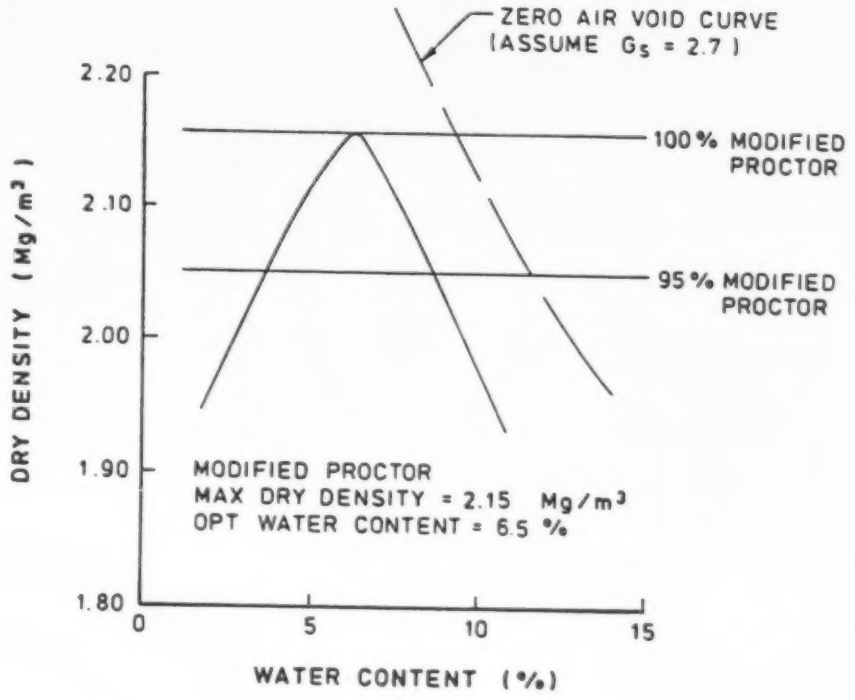
II.4.4.6 Diversions

As discussed previously in Section II.4.4.1, a diversion dyke had been constructed to channel surface runoff around the tailings impoundment

TABLE II.4.4-2

PHYSICAL PROPERTIES OF BENTONITE MODIFIED TILL, S.D. SITE

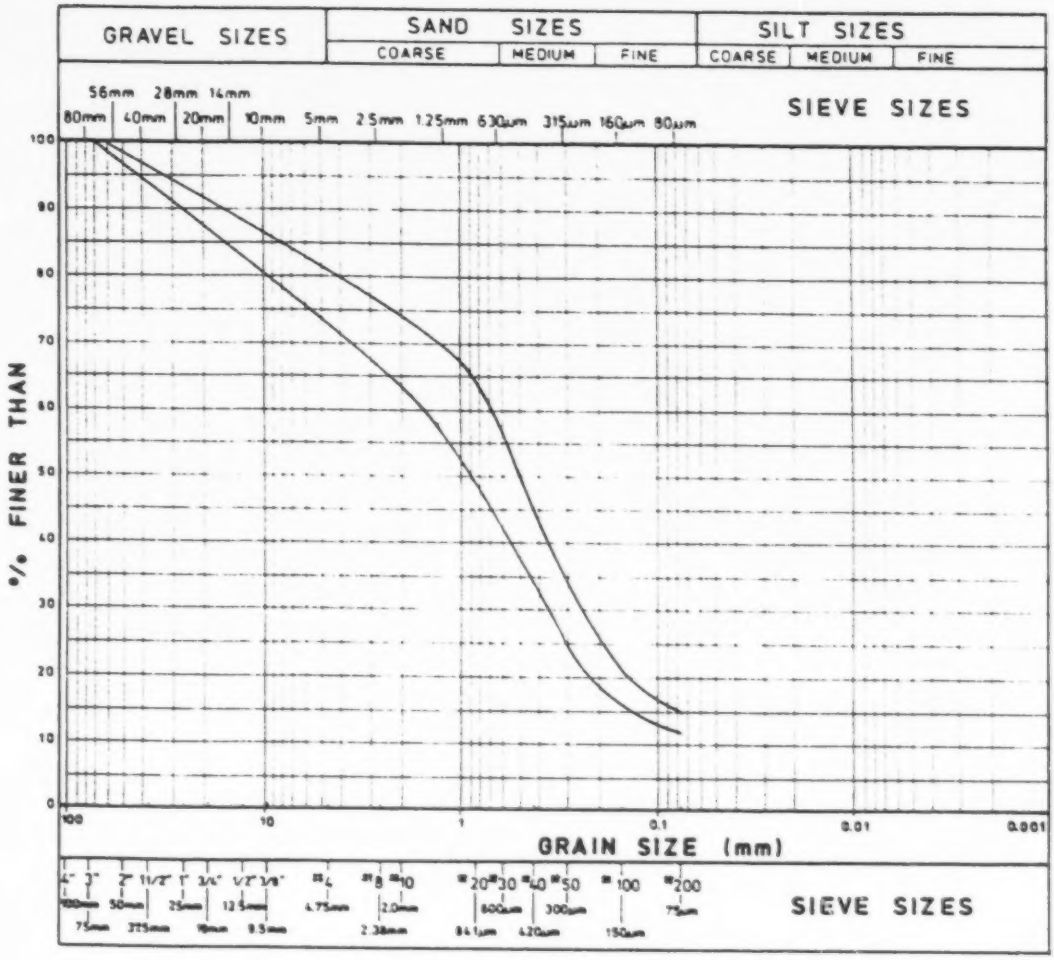
PHYSICAL PROPERTIES		COMPACTED SOIL-BENTONITE
GRADATION (% BY WEIGHT)	Gravel	13-26
	Sand	59-74
	Silt and Clay	13-15
SPECIFIC GRAVITY		2.59
IN SITU WATER CONTENT		8-11
ATTERBERG LIMITS	Liquid Limit	n/a
	Plasticity Index	0-28
COMPACTION CHARACTERISTICS (Modified Proctor)	Water Content (%)	6.5
	Dry Unit Weight (Mg/m^3)	2.15
HYDRAULIC CONDUCTIVITY (m/s)		1×10^{-8}



COMPACTION SPECIFICATIONS, BENTONITE MODIFIED TILL

(SASKATCHEWAN GENERIC SEMI-DRY SITE)

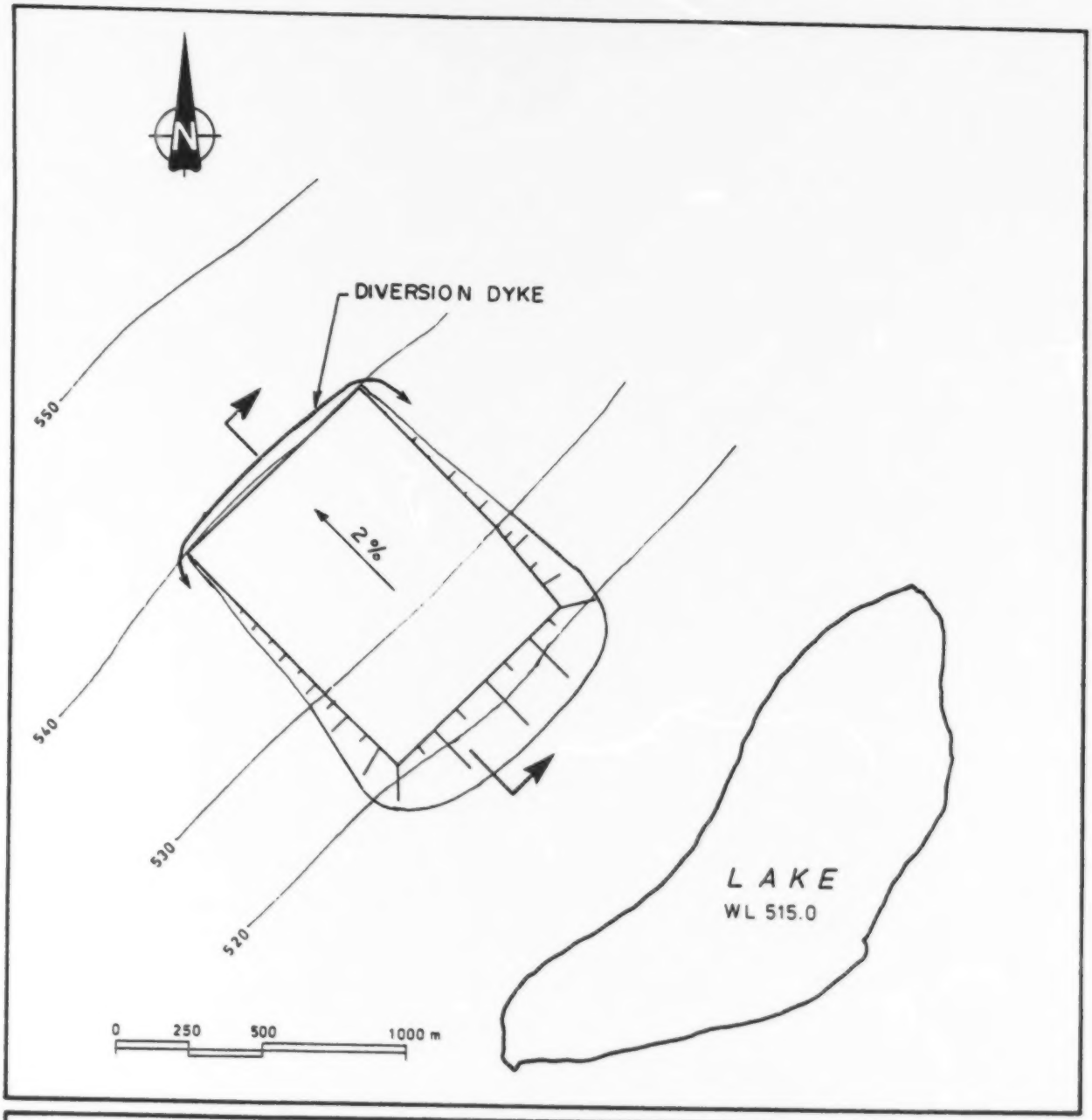
FIGURE II.4.4-3



GRAIN SIZE RANGE FOR BENTONITE MODIFIED TILL

(SASKATCHEWAN GENERIC SEMI-DRY SITE)

FIGURE 11.4.4-4

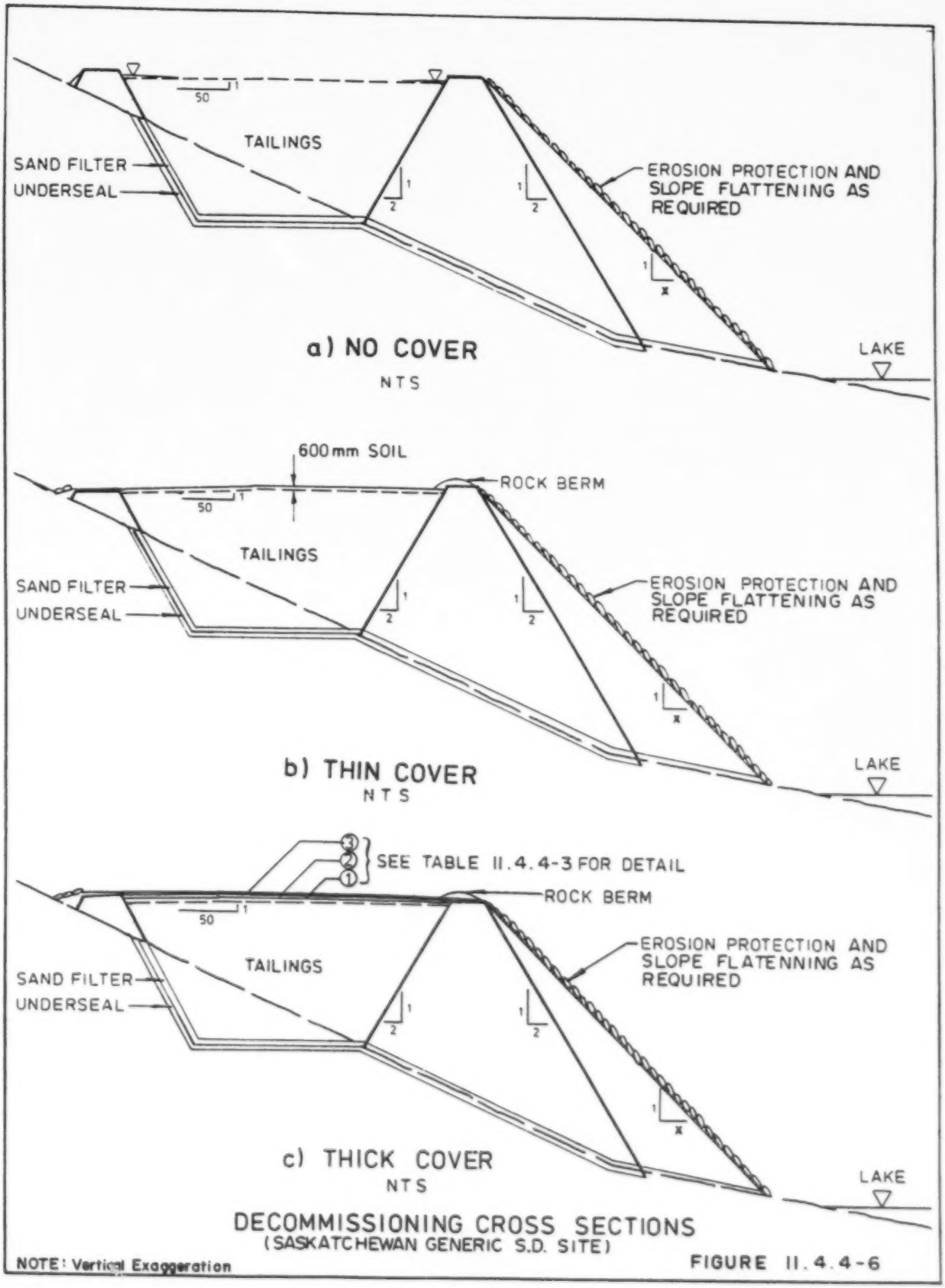


SITE PLAN

S.D. (SEMIDRY) TAILINGS DECOMMISSIONING SCHEME

(SASKATCHEWAN GENERIC SEMI-DRY SITE)

FIGURE II.4.4-5



DECOMMISSIONING CROSS SECTIONS
(SASKATCHEWAN GENERIC S.D. SITE)

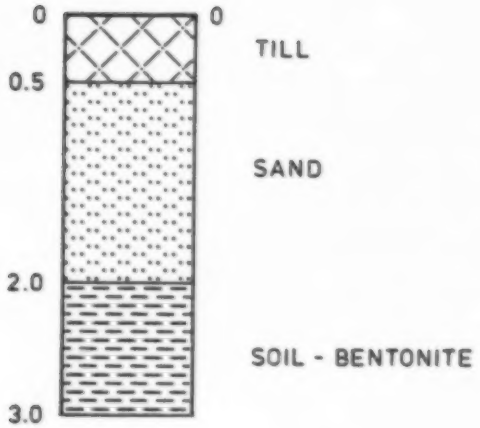
NOTE: Vertical Exaggeration

FIGURE II.4.4-6

TABLE II.4.4-3

CHARACTERISTICS OF THICK ZONED COVER,
S.D. SITE

ZONE	THICKNESS (mm)	PURPOSE	MATERIAL PROPERTIES
Till	500	rooting medium	random till
Sand	1500	drainage, capillarity break	outwash sand, <5% -75 um
Soil-bentonite	1000	radon barrier	4% bentonite, $k=10^{-9}$ m/s



COVER PROFILE

during operation of the facility. This existing dyke was used to divert surface drainage around the tailings deposit.

II.4.4.7 Seepage Control

Seepage was collected from the underdrainage system as the tailings consolidated. However, after flattening the side slopes, seepage collection was discontinued and is freely discharging to the surface water of the lake to the southeast.

II.4.4.8 Water Storage and Quality Control

Seepage and decant water was stored in lined treatment ponds during operations and monitored before discharge. No monitoring took place after decommissioning.

II.4.5 TAILINGS DEPOSIT CHARACTERIZATION

Design of the tailings impoundment facility required that the tailings slurry be deposited in thin layers over the filter blanket in a rotational sequence to produce a tailings beach which slopes towards the main embankment. This method enhances separation of liquid from solids, producing a laminated tailings deposit with a low permeability in the vertical direction. Because the surface of the tailings is free of ponded water, evaporation is maximized which enhances consolidation of tailings. Tailings have been discharged alternately from locations along the northeast and southwest embankments. The method of deposition results in little segregation of materials.

At the time of decommissioning, approximately 20 m of tailings were contained in the impoundment area. Based on the consolidation testing conducted on tailings samples, the estimated consolidation for the tailings with 600 mm and 3000 mm of cover is 2.4 and 3.0 m, assuming consolidation of the tailings also occurs due to their own weight. The estimated time for 50% and 95 % consolidation considering single drainage is 5.3 years and 30.0 years respectively.

II.5.0 REFERENCES

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